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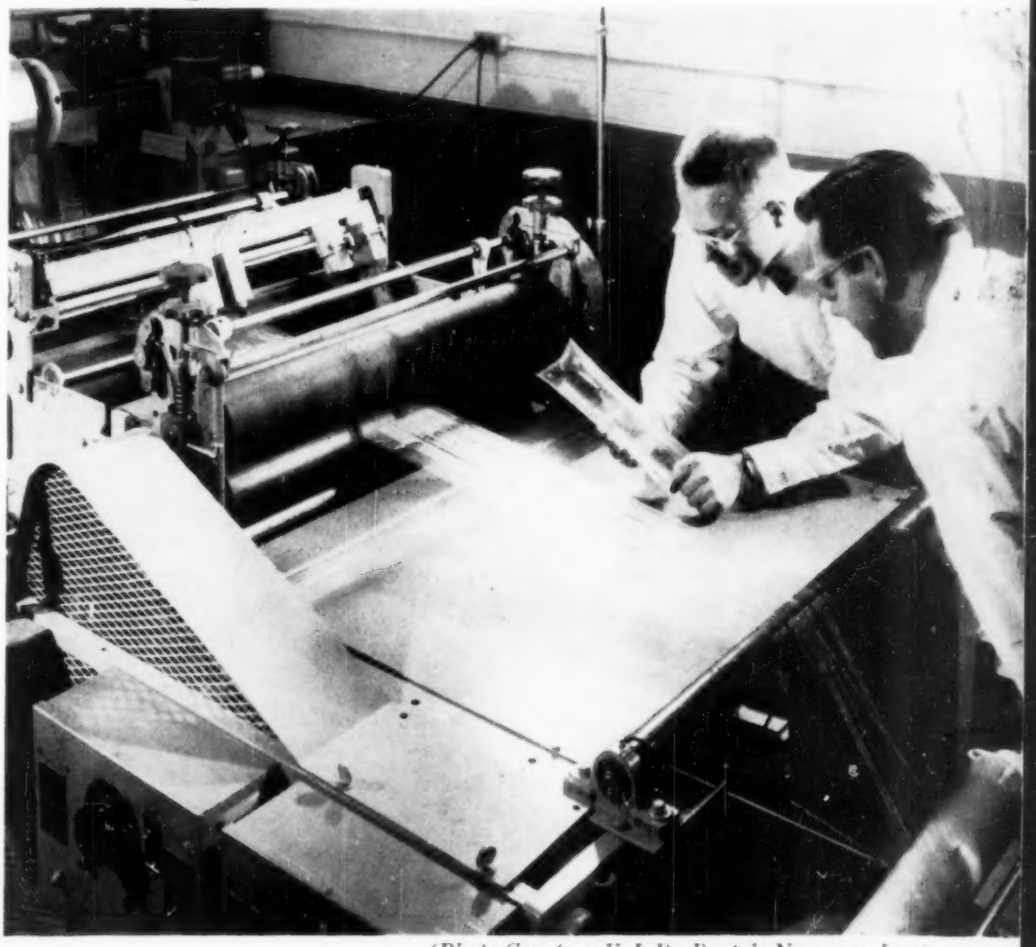
JOURNAL

VOLUME 12, NUMBER 2 • FEBRUARY, 1956

To Make Plastic Bags . . . .

Experimental Equipment Making Bags of Mylar Film



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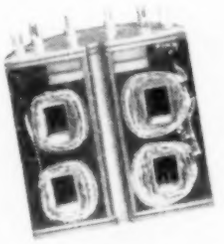
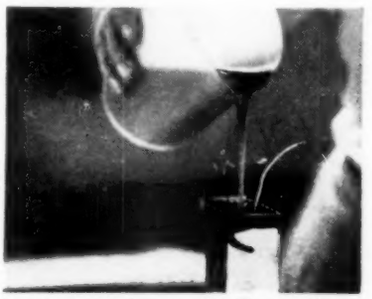
Miniature electronic components potted in Epon resin by Freed Transformer Company, Brooklyn, New York.



Section of magnetic amplifier coils embedded in Epon resin by Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.



Potting transformer with Epon resin at PCA Electronics, Inc., Santa Monica, California.

Because of their excellent mechanical and dielectric properties, Epon resins are important materials in electrical and electronic manufacture. Epon resins combine high strength with low shrinkage on curing and extreme dimensional stability.

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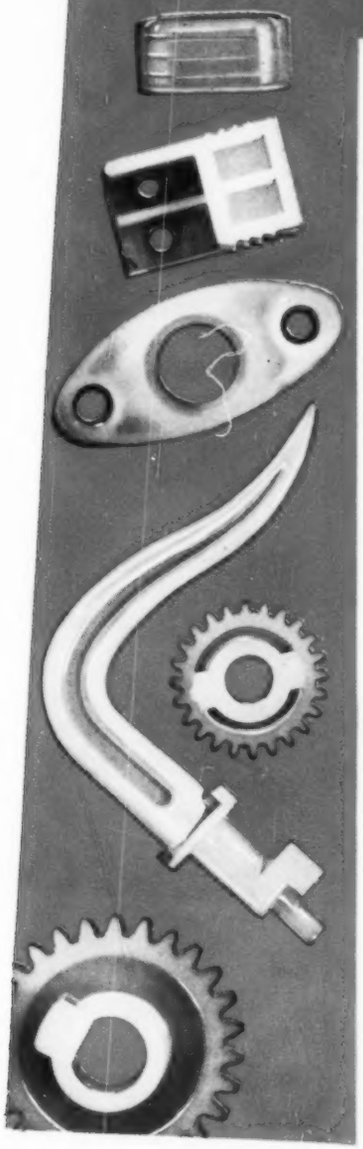

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U.S.I. POLYETHYLENE PROCESSING TIPS

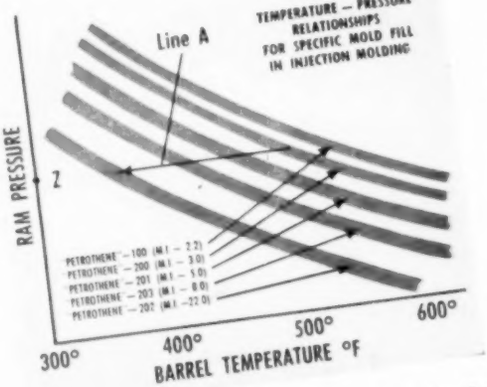
Increase production rates by choosing the right resin

Choice of the polyethylene resin with flow properties best suited for a particular application can make the difference between high or low profit to the injection molder.

Which is the best resin? This of course will vary from application to application, but here is some background information that will help you find the right answer for your application.

The curved bands in Figure 1 represent injection molding conditions for resins exhibiting several different flow properties. The lower the position of a resin's band on the graph, the higher the flow properties.

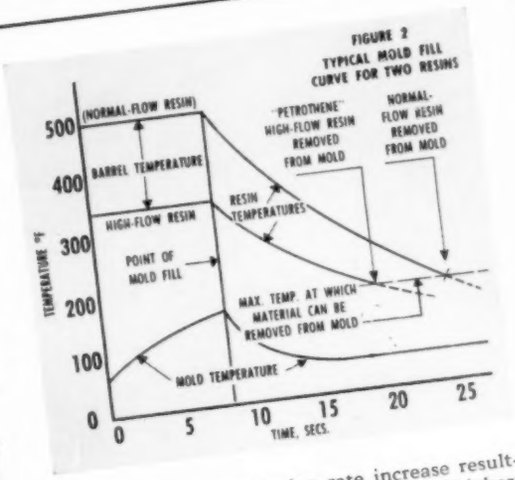
FIGURE 1
TEMPERATURE – PRESSURE RELATIONSHIPS FOR SPECIFIC MOLD FILL IN INJECTION MOLDING



These curves show that a molder can do the same molding job at a *lower* barrel temperature – without increasing his ram pressure – simply by going to a higher-flow resin. Line A, for example, shows that the job can be done at pressure Z with PETROTHENE® 200 at 500°F barrel temperature, can be done with PETROTHENE 201 at 470°F, PETROTHENE 203 at 430°F, or PETROTHENE 202 at 370°F.

What does this mean in terms of cycle time and production rates? Refer to Figure 2, which shows typical cooling curves for an injection molding cycle at two different barrel temperatures. The curve shows that the "normal-flow" resin, operating at a barrel temperature of 500°F in this particular mold, takes 25 seconds to reach release temperature, while the "high-flow" resin reaches this same temperature level in 21 seconds – a saving of about 16% in cycle time. Of course, these times and temperatures apply only to this particular mold. Other molds will have greater or lesser savings, but the same general principle applies.

FIGURE 2
TYPICAL MOLD FILL CURVE FOR TWO RESINS



Aside from the production rate increase resulting from this cut in cycle time, the use of higher-flow polyethylene resins has other advantages – 1. Higher surface sheen, 2. Lower warpage, 3. Less shrinkage.

One caution. When using high-flow resins, be sure that there is adequate back-pressure to eliminate the possibility of air voids appearing in the molded part.

Plant performance tells the story

Molders who have been using U.S.I.'s PETROTHENE 202 (Melt Index – 22) for molding large-size housewares report production increases of *as much as 35%*. Other high-flow types of U.S.I. PETROTHENE – types 201 and 203 – have been chosen because they give the desired degree of flexibility to the molded part, as well as for the production increase.

Call on U.S.I. technical service

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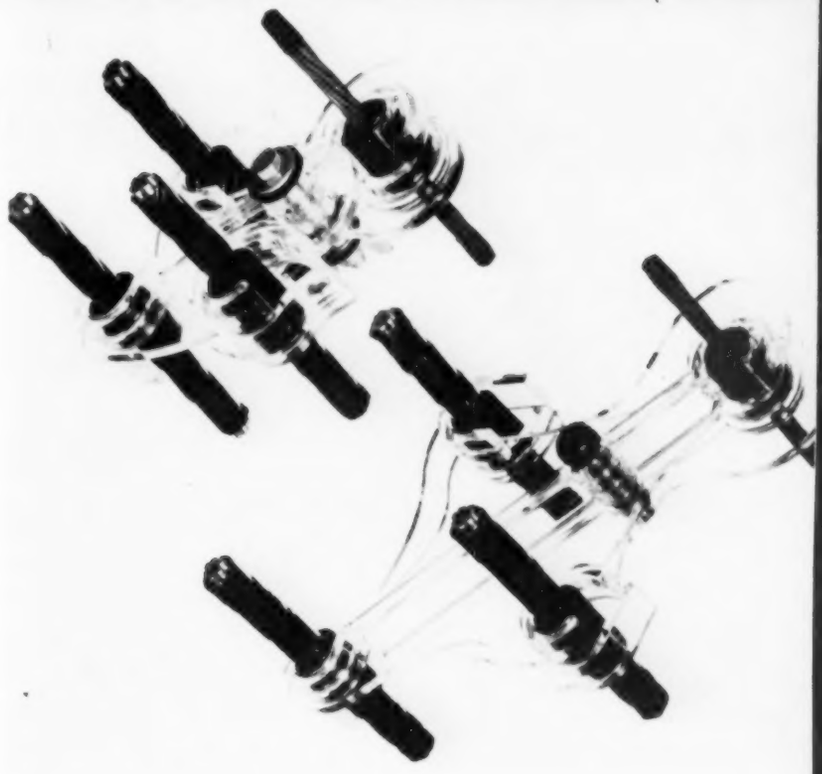

Two identical halves, molded in 1/4-in. thickness of weather-resistant Plexiglas molding powder, are joined by a single bolt to form the new Hendrix Ti-6 cable clamp which holds cables on 6-in. centers in power lines carrying up to 15,000 volts.

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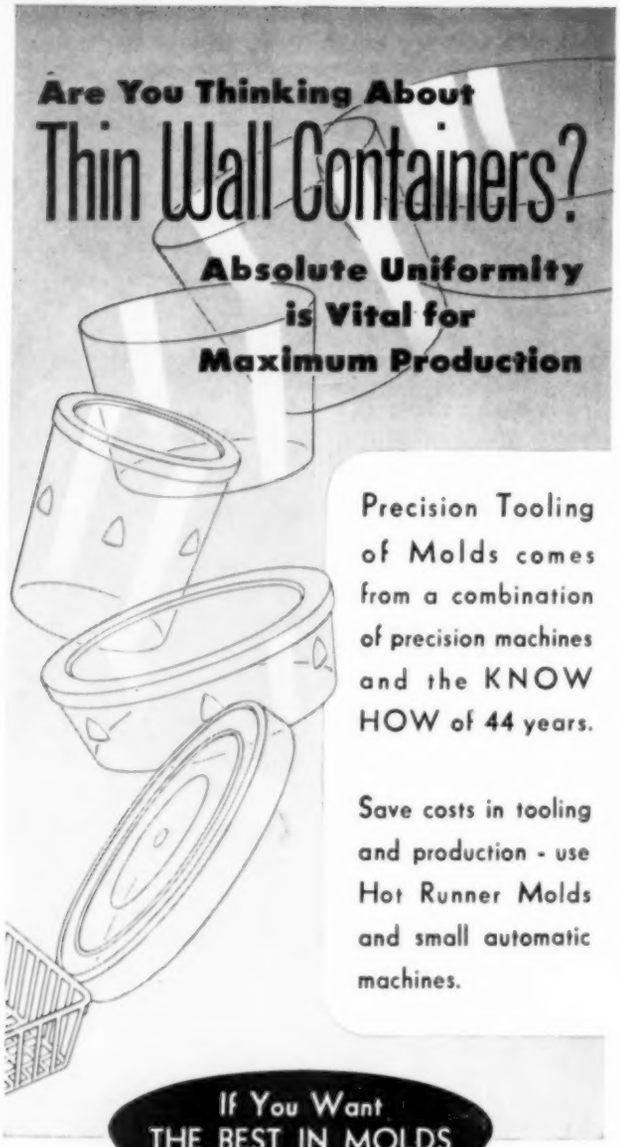
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Book Reviews . . . .

PRODUCT DESIGN HANDBOOK ISSUE FOR 1956

Published by: Product Engineering Magazine, McGraw-Hill Bldg., 330 West 42nd Street, New York 36, N. Y.

Annual Handbook issue contains a number of technical articles summarizing latest developments in a number of fields of interest to those engaged in design of machinery and other engineered products. Relatively small section is devoted to non-metallic materials (mostly plastics), and considerably more attention focused on topics such as: Power Transmission; Mechanical Parts & Design Analysis; Motors and controls; Electrical, Hydraulic, and Pneumatic Equipment. Like most technical magazine handbooks, this issue is loaded with advertisements. If you subscribe, you get it free.

Leon Brettler

HANDBOOK OF BARREL FINISHING Ralph F. Enyedy, 255 pages—$7.50. Reinhold Publishing Corporation, New York, 1955.

Although this book was primarily written for those in the metal working industry, the equipment and many of the procedures described in it can be applied to the finishing of plastic parts. The book is of particular interest to those finishing thermosetting plastics, where excessive flash frequently remains on the molded parts after the molding operation. It clearly illustrates when and how to use tumbling or barrel finishing to deburr, color, polish, or burnish.

The author describes such operations as removing flash without excessive radiusing, and the softening of a bright glaring plastic finish to a satiny glow. More than 150 specification sheets give detailed methods of finishing a large variety of parts.

Since much of the information appears in print for the first time, the book is unique.

Bernard Diggins

Low Cost Molds for Plastics, Rubber and Allied Industries

DEVCON C, a combination of approximately 80% aluminum and steel and 20% plastic, can be poured or formed into any shape. It is now being used for making inexpensive plastic and rubber molds, embossing dies, tools, jigs and fixtures, filling holes in castings, caulking around steel plates, and for many other applications where high strength at elevated temperatures is essential. Tremendous savings in time and money are possible with this new material.

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Write to Chemical Development Corporation, Danvers, Mass. It is intended primarily as a low-cost method of making molds for the plastic, rubber and allied industries.

Industry News

Perry Plastics

Perry Plastics, Inc. is proud to announce that their new 40,000 square foot building located at 14th and Marshall Drives, Erie, Pennsylvania is rapidly nearing completion. This modern, one floor building, when completed, will be one of the most modern and completely equipped molding plants in the country. The use of plastics in the building is extensive and, as a result, the building itself, exemplifies rapid progress in the plastics field during the past decade.

Since its establishment in 1946, Perry Plastics, Inc. has shown steady growth, presently operates 24 molding machines producing injection, compression, and molded fiberglass products. Employees presently total approximately 200 and supply a variety of molded plastic parts and assemblies to refrigeration, automotive, electrical and governmental customers. Several new machines are on order and will be placed in the new building in keeping with the company's policy of operating only the newest and most efficient equipment.

The officers of the company are Jerry C. Stokes, president; E. H. George, Executive Vice President-Treasurer; Walter E. Hindman, Secretary. The Board of Directors consists of Mr. Stokes, Mr. George, Mr. Hindman, Mr. William Conners, Mr. Edward Greener and Mr. S. C. Seley, Sales Manager of Perry Plastics, Inc.

The company plans to begin moving operations about January 1, 1956 and expect to have all production operations removed from the present plant at 18th and Ash Streets, Erie, Pennsylvania by the middle of January, 1956.

Oils, Lubricants

Hydraulic oils, lubricants and packings are the subject of a 4-page catalogue put out by E. F. Houghton Co., 303 West Lehigh Ave., Philadelphia 33, Pennsylvania.

Compounding Colors

Colors for vinyl compounding are described in technical sheets offered by Claremont Pigment Dispersion Corp., 110 Wallabout St., Brooklyn 11, N. Y.

Skeist Consultant

Irving Skeist, now a chemical consultant specializing in plastics offers a comprehensive 18-page report on plasticizers on request, 14 Edgar St., Summit, New Jersey.

Tensile Strength

"The Tensile Strength of Elastomers," by G. R. Taylor and S. R. Darvin, a 24 page reprint from the Journal of Polymer Science, may be had by writing to Mellon Institute, 4400 Fifth Ave., Pittsburgh 13, Pennsylvania.

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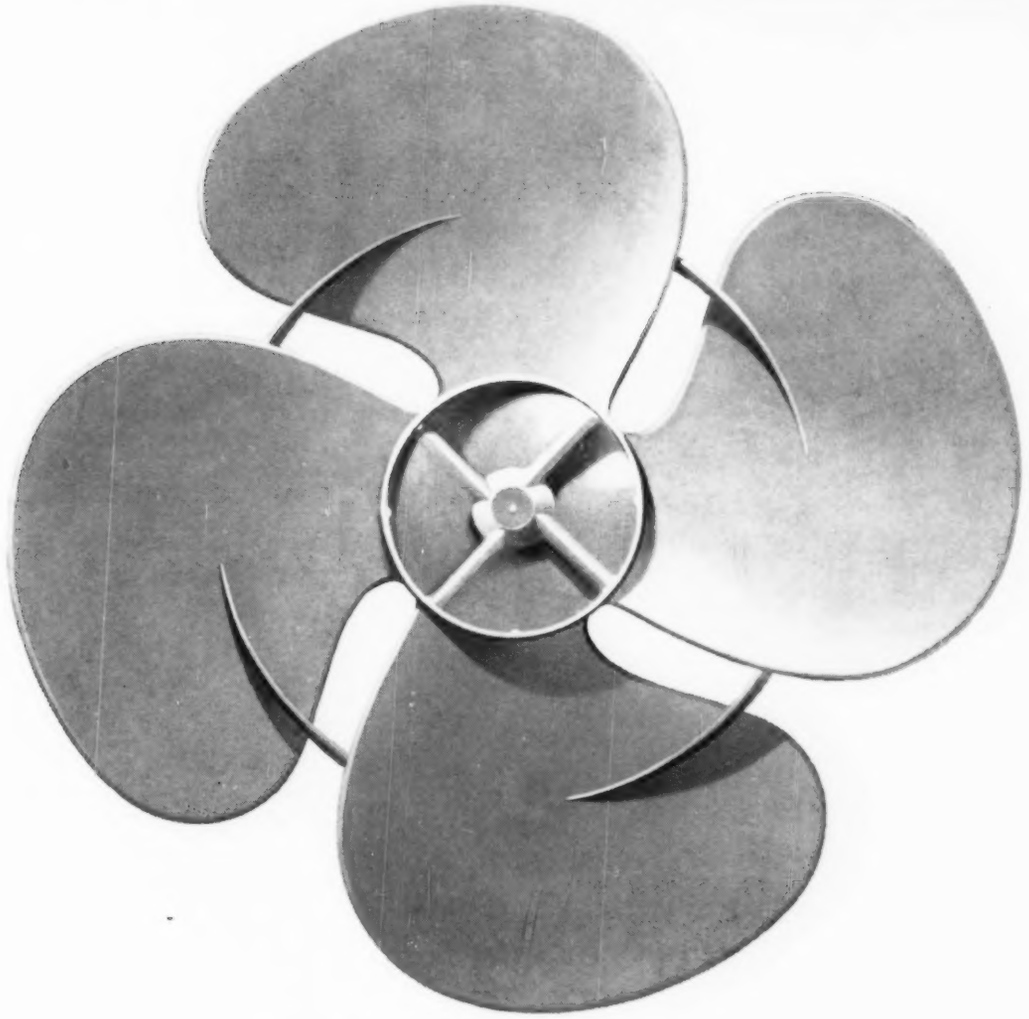

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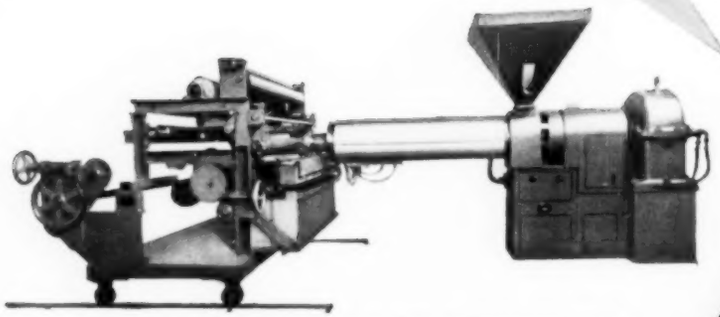

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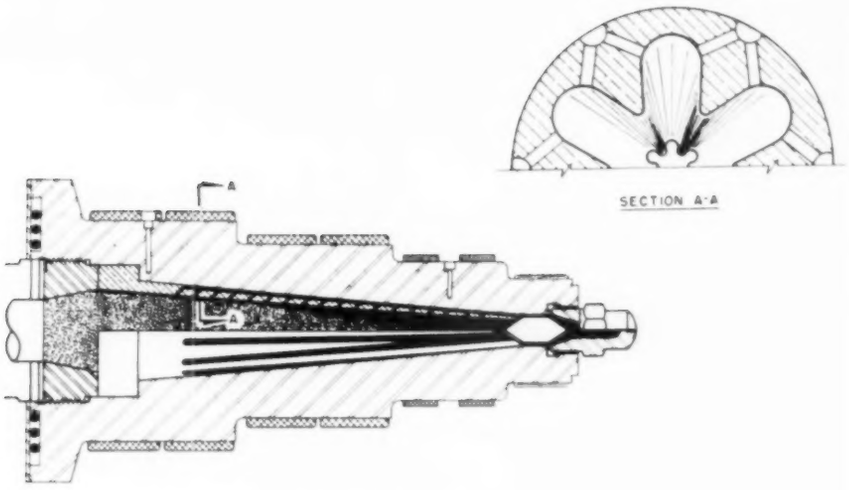


Fig. 1 Cross-section view of the first type of melt-extraction heating chamber.

The Maccaferri Injection Molding Heating Chamber

Mario Maccaferri
Mastro Plastics Corp.

Robert B. McKee, Jr.
Dow Chemical Co.

THE HEATING CHAMBER has often been described as the "heart" of the injection molding machine. This statement is true in the sense that thorough, uniform heating of the plastic charge is a necessity for the proper function of the whole machine. Indeed, with some plastics, it is not possible to mold at all without an efficient heating chamber. Because the definition of efficiency is a necessary first step in its improvement, we have gone to a great deal of time and expense to develop reliable tests of efficiency. To put this efficiency test to use, we have examined nearly every standard type of heating chambers. These designs with large differences in method, have all used the same basic type of flow. The information thus collected was condensed and our findings were presented to the SPE a year ago.

As the name implies, the heating chamber is first a device to heat plastic. Specifically, to heat-soften the plastic enough to permit quick, easy filling of a mold. Usually, a rather long time is required to heat the plastic to molding temperature because of its low thermal conductivity. This can be done more quickly by increasing the temperature difference between the heating surface and the required plastic temperature, but the plastic next to the heating surface will reach the wall temperature and may be damaged if the wall is too hot. This unavoidable fact that some of the plastic will always be heated to the wall temperature places an upper limit on the heater setting.

The "ceiling" on a chamber temperature may also, in many cases, be dictated by the shrinkage which results from high temperatures.

It is equally necessary that a lower limit be placed on plastic temperatures. The plastic which stays farthest from the source of heat will remain the coldest; when flowing through restricted gating systems, or the thin sections of a mold, this cold slug will have the same general effect as a large log in a small stream. In this way, we see that while the plastic must not be heated above a certain temperature, we would like to bring the whole mass as close to that temperature as possible.

A common, and usually successful way, of meeting the heat transfer problem is to use a heating cylinder that was originally designed for much larger shots. For example, the worst 12 oz. cylinder ever made will do fairly well on a 2 oz. shot. The trouble with this solution, aside from the nuisance of purging out that extra material with every color change, and the limit of space on the machine, is that there is a connection between the maximum temperature and the maximum time. That is, the plastic (any plastic) will stand a low temperature for a long time, but will stand a high temperature for only a short time. And, the higher the temperature, the shorter the time. Because of the larger volume, it takes much more time for a given shot to get through a large cylinder, and some of the plastic will be at heater temperature all of that time. So, for best results, our heating chamber should be arranged to keep the plastic under heat for a minimum length of time.

Quick Filling Mold

We have stated that the main reason for heating plastic is to reduce the viscosity and permit quick filling of the mold with a minimum of pressure. The speed of filling is important, because the plastic is losing heat to the mold walls and forming a frozen "skin." It is possible to fill quickly enough to prevent formation of this skin by generation of frictional heat, or to keep its thickness to a minimum.

Speed in filling the mold can not only make possible a reduction in frozen stress and an improvement in surface finish, but larger pieces can be molded with the same clamp, since we are actually using less pressure at the end of the injection. I am sure that you all know of molds which cannot be run without using all the speed of which the machine is capable; there are also many molds which won't run now, but which would run if we could just fill them fast enough.

The advantages of fast filling put a severe requirement on the heating chamber. It does little to do a good job of melting if the melter soaks up so much of the available pressure that there is not enough left to fill the mold. Even thoroughly melted plastic requires pressure for flow, and this pressure requirement can be high when a mold is filled in less than a second. So our heating chamber must use a minimum of pressure to do the job.

This paper was presented at the SPE 12th Technical Conference.

Fig. 2 Improved design of the melt-extraction heating chamber.

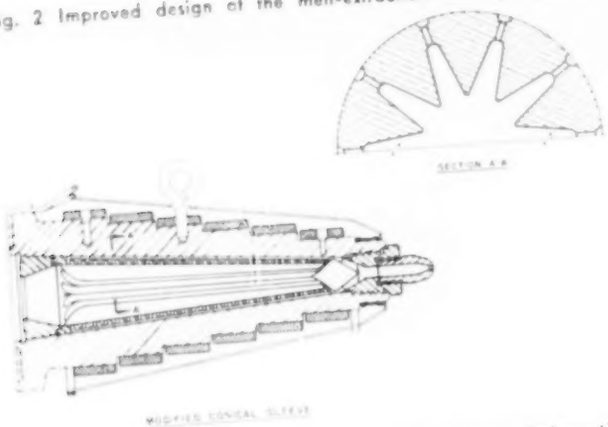
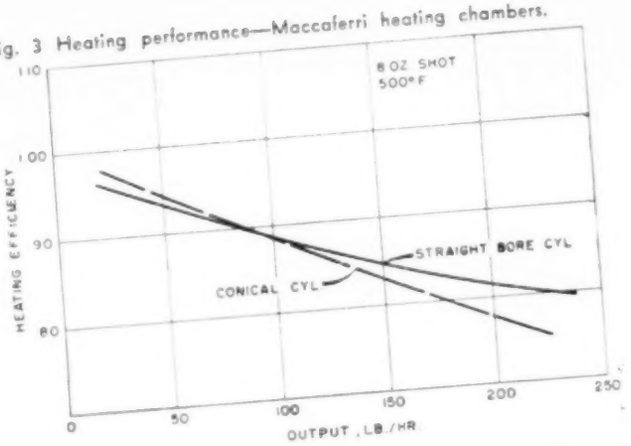


Fig. 3 Heating performance—Maccaferri heating chambers.



The problem takes more definite shape: bring the plastic up to temperature quickly; without using excessively high temperatures; with minimum pressure loss. The question is, how?

We have mentioned that the time available for the heating cycle is limited. It is possible to lengthen the heating cycle by providing extra volume in the chamber, so that each shot would stay under heat for many cycles. This technique works fine for metals, which are good conductors of heat. On the other hand, low thermal conductivity is a distinguishing feature of plastics. For instance, under the same conditions, steel will conduct 440 times as much heat as polystyrene. If we were to raise the average temperature of a slab of polystyrene to 450°F., using a wall temperature of 500°, it would take the following times:

For a slab 1/2" thick: 921 seconds
For a slab 1/4" thick: 230 seconds
For a slab 1/16" thick: 14 seconds
For a slab 1/32" thick: 3.6 seconds

These figures show graphically how useless it is to depend on "soaking" the plastic in a thick section to get uniform temperature.

A New Principle

Why not, then, build a heating chamber in which the plastic was smeared against the heating surface to a 1/32" thickness? To do this with a standard spreader-in-cylinder arrangement would result in a gigantic pressure loss. Any configuration that has this thin separation between heating surfaces is bound to have a high pressure loss because of the "drag" of those surfaces. But suppose that we could heat just the outer 1/32" surface of a solid block of plastic and then remove this heated material?

A demonstration to illustrate this melt extraction principle might use two short pieces of glass tubing and a hot plate. The glass tubes should be identical except that one has a smooth, square bottom which is sealed to the hot plate, while the other has a rough, serrated bottom which will allow any liquid in the tube to leak out. Now put two identical pieces of wax into the tubes, and allow the wax to melt.

The wax that was put in the tube with the serrated bottom will melt and run out, while the other tube will have quite a good sized chunk of solid parrafin in it. The reason for this is that in one case the molten wax ran out as it was melted, permitting the cold, solid material to remain in contact with the heated surface. When the melted wax is not permitted to leave, it forms a barrier between the hot plate and the unmelted wax. This demonstration, if you do not have the glass tubes, can be set up by using two ice cube trays (full of ice). Tilt one tray so that the water can run out as the ice melts, and leave the other on a flat surface.

Of course, glass tubes and hot plates do not belong in a molding machine. For a more practical shape, substitute a heated, perforated, metal cone. Now as the solid plastic is forced into the cone, molten material will come out the holes (like riced potatoes). The amount of melted material that can be extruded this way before we find ourselves trying to push solid material through the holes will depend on two things: 1. the length of time that it is allowed to soak between plunger strokes, and 2. the area of the heated cone.

In practical application, the heated cone, or sleeve, is introduced into a heavy steel jacket or cylinder, on which heater bands are clamped. The material which comes out through the holes is conveyed to the nozzle through grooves which have been cut into the outside of the cone. Figure 1 shows a cross-section of the first type of melt extraction cylinder; the top half shows the cross-section of the sleeve and you can see the granular plastic filling up the space in the center, melting against the sleeve, and going through the holes into the channels in the outer surface of the sleeve. The outside of the sleeve is shown in the lower half of the cutaway drawing. To increase the heating surface area, the sleeve has flutes, which are shown in the section view. The conical shape has the advantage of naturally tight assembly and good conversion of injection pressure to the walls of the cone.

Larger Heating Surface

To get more internal surface, a second design was built (actually, there were six modifications) with a straight bore and ten internal flutes. Figure 2 shows a cross-section of the chamber both lengthwise and crosswise. The main difference is the straight bore, giving about three times the surface area of the conical model. These cylinders were both tested for plasticizing performance using the test method we have developed wherein the temperature of the plastic issuing from the nozzle is measured with a special thermocouple. This plastic temperature is compared to the heater setting by the ratio

$T_p - T_o$ (Plastic temp. minus hopper temp.)

$T_h - T_o$ (Heater temp. minus hopper temp.)

which we call heating efficiency. This heating efficiency, or temperature rise ratio, as it is sometimes called, is one value for any particular output rate (lb./hr.) and is not affected by the heater temperature.

The plasticizing performance of the two cylinders

Fig. 4 Pressure loss—Maccaferri cylinders.

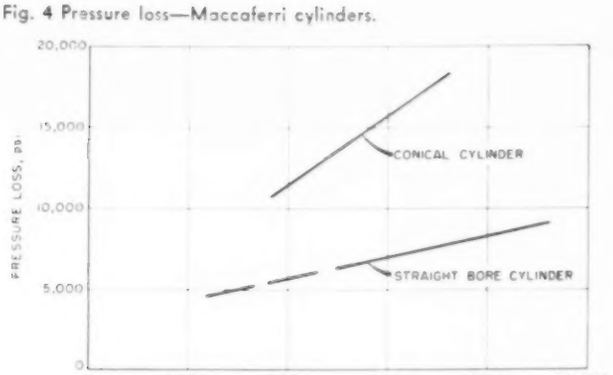
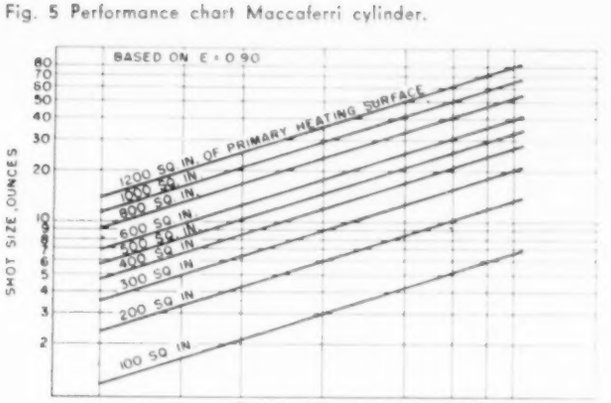


Fig. 5 Performance chart Maccaferri cylinder.



is shown in Figure 3 as heat efficiency plotted against output rate. Good uniformity of temperature is attained at an efficiency of 0.8, and this has been used as a standard; that is, the lb./hr. output at this efficiency is called the rated output. As you can see, these two cylinders both show a rated output about 200 lbs./hr. which is equivalent to a 13.5 second cycle with a 12 oz. shot. This sort of performance, while beyond the capability of a standard heating chamber, is within the mechanical ability of the newer machines and well worth while shooting at. The rated capacity of 12 oz. machine heating chambers in use today seldom exceeds 50 lbs./hr.

Referring to Figure 3 again, the straight type chamber showed only a small improvement in plasticizing ability over the conical model, despite its greatly increased heating surface. This is apparently due to the conical shape giving: 1. a better fit between sleeve and outer barrel; 2. more uniform pressure between plastic and heated wall, and 3. thicker fins on the conical model, which are better able to carry enough heat to the plastic.

Presssure Loss

The second important phase of performance is pressure loss, which we evaluated by purging the machine on a constant cycle through a pressure gauge and adjustable restriction mounted on the nozzle. The pressure loss of the straight bore model at this condition is much lower than that of a standard type machine (Figure 4), but the conical model showed a high pressure loss. The most likely reason for this extra pressure loss is that we are operating in the output range where the plunger was trying to push solid material through the holes. As we said before, the size shot that can be had in this type of heater depends on the cycle and amount of surface area.

Happily, this capacity for shot and cycle is easily calculated. We assume that the shot is spread uniformly over the heated surface (not including the area of the holes). This gives the thickness of the heated layer. Then the time necessary to heat this layer to an "efficiency" of 0.90 is figured using standard heat transfer calculations. This efficiency figure means that at a heater temp. of 500°F, the average plastic temperature will be 458°F, and fluid enough to flow easily through our channels to the nozzle, sprue, and mold. The results of many such calculations are combined in Figure 5.

To get the plasticizing performance of the conical type of chamber without the high pressure loss encountered in the first model, a third design is now under construction. In this design, a shallow cone is used and the heated surface has been increased to more than in the straight model. Probably, optimum performance will be realized by correct selection of the cone angle, and, of course, provision of enough heated surface as indicated by Figure 6.

Although heating efficiency and pressure loss are of main importance in heating chamber design, other factors must not be neglected. Uniform flow velocity through the chamber is necessary to prevent localized overheating and permit change of color and/or type of material. Flow uniformity is gotten by careful design; it is possible in this type of cylinder to eliminate all corners, that interfere with steady flow. Specifically, the holes leading to the outer flow passages must be polished and the corners broken; the passages in the outer surface of the shell must be smooth. Good workmanship must be the rule, as with the construction of any heating chamber.

Stray slugs of cold material which sometimes slip by the heating surfaces and into the nozzle (by-pass) are a problem with standard types of heating chambers; these slugs play havoc with a precisely adjusted molding cycle. This sort of thing is prevented in the melt extraction chamber by the smallness of the holes through which the molten plastic passes.

This heating chamber is not fool proof; it must be carefully designed and painstakingly built to deliver the performance of which it is capable. The heater bands must be correctly sized and instrumented to prevent overheating. As always, the rest of the molding machine should be adjusted and operated by experts. But this design of heating chamber has the potential to revolutionize many molding operations.

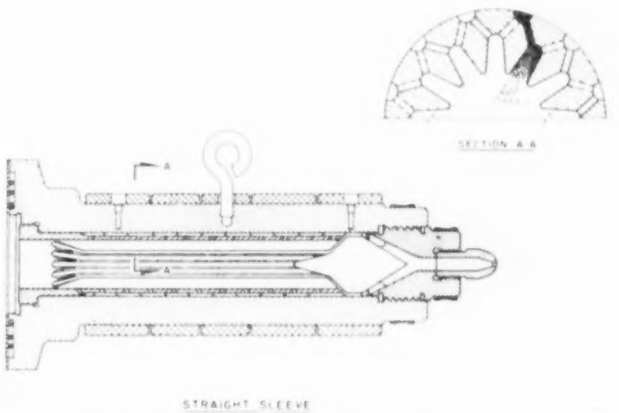


Fig. 6 Design for provision of sufficient heated surface.

Injection Molding of . . .

Vinyl Chloride Dry Blends

C. W. Bulkley
Monsanto Chemical Co.

INJECTION MOLDING OF polyvinyl chloride is not new. It has been done ever since World II, when rubber was so scarce that PVC was drafted as a substitute. Rubber-like PVC turned out to be a satisfactory molding material for many noncritical items for which use of natural rubber could not be justified.

As time went on and experience was acquired, some of the initial problems were overcome and many of the advantages of PVC began to be realized.

1. No curing was required. Cycles were much shorter and small pieces could be molded more economically with PVC.
2. The material could be injection molded and because of the closed mold, less flash trimming was required.
3. PVC is resistant to oils and greases. This makes it useful near machinery, automobiles, aircraft, or heavy equipment, and in kitchens. PVC also has excellent resistance to many chemicals and solvents.
4. Oxygen and ozone do not attack and crack PVC the way they do natural rubber. Outdoor aging is excellent, when the material is properly formulated.
5. PVC can be colored almost any color with a brilliance not possible with rubber. It can also be transparent, translucent or opaque. Luster and gloss are also far better, and the feel is smoother to the hand.
6. The physical properties of vinyl chloride are better than those of natural rubber in many ways, and abrasion resistance is excellent. Thinner cross sections can be used and, hence, sharper undercuts are possible than could be obtained with rubber. For example, a vacuum cleaner brush holder can be die cast with inexpensive metal, and a colored vinyl cover and bumper snapped on. This also means less weight.
7. One of the most significant differences is the better electrical properties of PVC, manifested chiefly in its insulating characteristics. The volume resistivity is higher; 1 x 10^{13} ohm-cm at 50°C is typical.

Molded vinyls do have some limitations such as maximum operating temperatures. The normal compound, as used in electrical applications, is rated at 60°C, although some compounds are suitable for 105°C uses. Certain plasticizers may either volatilize or undergo chemical change if temperatures are sustained at higher levels for long periods.

Vinyls do not have the elasticity or spring-back of rubber, but tend to creep back to the original shape after deformation. Plastic memory is very strong in this sense (unless the product is deformed under heat) but is slower acting.

With the advantages of good color and appearance, smooth feel, high strength, durability and production cost saving possibilities, it is no wonder that more than 6,000,000 pounds of PVC are injection molded yearly and that the field is growing rapidly. Let's take a look at a few of the items molded from PVC.

In the electrical field there are lamp cord plugs, television yoke insulators, automotive distributor cap nipples, battery clip insulators and electrode handles. An assembled television yoke is shown in Figure 1 along with these other applications. Many other interesting electrical uses have been developed.

Closely related to the strictly electrical uses are molded PVC parts for electrical appliances, such as vacuum cleaners, floor polishers and kitchen mixers. Figure 2 shows several pieces molded by the Hoover Company for their vacuum cleaners. Bumpers and drain troughs can also be molded for refrigerators.

Vinyls are practical for sporting goods and toys, too. Figure 4 shows a tractor and a racing car, which will not break nor scratch furniture easily. The PVC doll's shoe is more colorful and durable than other types of shoes. In some cases toy animal faces and cartoon characters' faces can be injection molded more economically, where high volume output is involved, than they can be slush molded from plastisols. Bicycle handle grips are a natural for PVC with better ability to "take it" than rub-

Fig. 1 PVC electrical applications include outlet plugs, battery clip insulators, distributor and television parts.

This paper was presented before a meeting of the Eastern New England Section of the SPE.

ber of equivalent cost. In the aquatic field there are goggles, as shown, and swim flippers.

Uses not shown in photographs include luggage welting with molded corners, better able to take the strain of cold weather than extruded ones bent around corners. Suitcase handles are molded of PVC around metal inserts. Typical household applications are hair curlers, toilet seat bumpers, coasters, fly swatters, drain trays and garbage containers. In the military area, interesting developments are the rust inhibited injection molded projectile fuse thread-protector and the cartridge clip cover. Agricultural uses include irrigation gaskets.

In the injection molding of these items, essentially the same equipment and techniques that are used for other thermoplastics, such as styrene, can be used. However, certain basic differences must be borne in mind.

1. Elastomeric vinyls can be formulated for many different end uses, in hardness varying from 50 to 100 plus on the Shore A Durometer scale. PVC can be filled with calcium carbonate, clay and other fillers, where styrene is normally only pigmented. PVC can be plasticized, but styrene cannot be similarly plasticized. Furthermore, there are many different types of plasticizers and mixtures of plasticizers, as well as amounts used. Molding conditions must be adjusted accordingly.
2. PVC must not be melted by the heat of the cylinder alone, but must be worked and sheared into a uniformly heated homogeneous mass.
3. The most significant difference, however, lies in the tendency of PVC to decompose under sustained exposure to high temperatures, producing brown or yellow stains or streaks, or black spots in the product. Hydrochloric acid is released during this process, which in turn catalyzes further and faster breakdown and carbonization of the stock. It will also attack metal surfaces unless they are corrosion resistant, if the reaction is allowed to proceed. Cylinders and torpedoes should be chrome plated. Hastelloy is often used when volume justifies the added cost.

This problem of decomposition is made more difficult to combat by the high resistance to heat transfer of vinyl chloride, since adequate heating and working is necessary for complete plasticization. Yet the tendency to breakdown limits both temperature and cycle time.

1. An important first step is, of course, to stabilize the PVC as well as possible. Lead stabilizers such as basic carbonate of lead and tribasic lead sulphate are excellent, when toxicity and sulfur staining are not a problem. There are also many barium-cadmium and tin stabilizer systems which have proved very effective for injection molding compounds. These are less toxic and less subject to staining, if properly selected.
2. The heating cylinder is the heart of the molding machine, and the type of spreader used is important with PVC. Streamlining is necessary to avoid dead spots where material might hangup and decompose. Hot spots must be avoided, too. The fin type of spreader or torpedo is not generally as desirable as the drilled sleeve type, since the latter permits some working of the stock in the cylinder. A multiple heating zone arrangement is better than single zone heating. Heating control instruments should be very sensitive and not permit over-riding of temperature.
3. A restriction of some sort is required in the nozzle. It is common practice to place a dispersion disc or breaker plate at the inlet to the nozzle. This should be a disc about ¼" thick with holes of approximately .040" diameter spaced uniformly over the surface. These holes should be tapered or countersunk to promote smooth flow and to eliminate dead spots.
4. The nozzle should be heated to keep the material from cooling too rapidly on its way to the mold.
5. Full round runners and small gates are recommended. The gate size is quite critical and must be determined by trial, starting very small and gradually opening it until best results are obtained. Sharp corners should be avoided in the flow to the mold.
6. The mold temperature should be controlled by circulating hot water to maintain it at from 125 to 150°F. High temperature helps gloss and smoothness, and low temperature does not always permit a faster overall cycle.
7. In starting up, it is advisable to set cylinder temperatures low, at around 310°F to 320°F and work gradually up to the optimum temperature. Generally the rear of the cylinder is kept 10 to 20° cooler than the front if equipment permits. Stock should be injected into an open mold until equilibrium conditions are established in the machine and until previous material is properly purged.

Fig. 2 Parts for the Hoover vacuum cleaner molded of PVC.

Fig. 3 Sporting goods and toys offer a wide field for PVC.

Then the first molding can be made. Short cycles are used in starting up, and longer ones are used as needed, but only up to the point at which breakdown occurs. It is important to mold for a long enough period to permit equilibrium conditions to be reached in the cylinder. Otherwise, the effect of any change in temperature or cycle cannot be properly evaluated.

8. If signs of decomposition occur, it is necessary to open the mold and purge the machine by continued manually operated shots until it clears up. It may not be necessary to reduce temperature or cycle time, since the problem may have been caused by long exposure of some of the material which was purged, and a fresh start can be made.

   Over a long period of time a lining of decomposed material tends to build up on the cylinder wall. This serves as an insulator, such that more heat is required. This condition grows worse, and after about two weeks of steady operation it may be necessary to shut down and clean both the torpedo and the cylinder. Otherwise pieces of carbon may break off and clog the gate.

   It is important not to allow material to stand long in the cylinder at high temperatures. During temporary work stoppages or lunch periods, and at the end of shifts or runs the heat should be shut off and the material purged until the temperature of the stock is below 250°F.

9. Styrene is an excellent purging material, and when it is desirable to run a styrene job after vinyls, it should be shot through at the same temperatures used for the PVC until the cylinder is clean. After this, temperatures can be increased, but purging should continue until no trace of the PVC shows up in the styrene. Clear styrene is best for this purpose.

Dry Blend PVC

So far, this has been a discussion of vinyl chloride in general. However, there are two physical forms in which PVC can be used in injection molding. One is the more commonly known pelletized form, and the other is the more recently developed dry blend.

Now the difference here is more than one of particle size; it lies in the extent of plasticization and method of processing. The pellets are cut by a dicer from strips of plastic that has been completely fused and compounded in a banbury and millroll compounding line. Temperatures in that process run as high as 350°F.

The dry blend, on the other hand, consists of a blend of special PVC resin with plasticizers, stabilizers, fillers and lubricants made in one of several types of blenders, of which the ribbon blender is most common, with temperatures not exceeding 240°F. The plasticizer is absorbed by the resin while fillers, stabilizers and lubricants cling to the surfaces of the resin particles. Dry blend feels dry and is a free flowing sandy material, easy to handle in injection molding equipment.

1. Of the many advantages of dry blend over pellets, one of the most important is the lesser heat history acquired in processing, which makes it less quick to decompose in the molding machine.
2. Another benefit is the smaller inventory made possible since natural dry blend can be dry colored much the same as can styrene fines, whereas good color dispersion and matching is very difficult with natural pellets. There are many colorant suppliers who furnish color dispersions or concentrates which can be tumbled into dry blend to give excellent color results.
3. Aside from the smaller inventory, it is even more important not to be dependent upon ready availability of pellets in a particular special color for a rush job.
4. With dry blend, it is easier to fill a difficult filling mold, since it seems to flow more readily around corners and into narrow spaces. For example, we have seen a case where dry blend would fill four cavities when pellets gave a short shot in the fourth. This may be partly due to the smaller particle size which permits quicker and more uniform heating.
5. The fifth and greatest inducement to a molder to use dry blend, however, is the savings which are possible in material costs through purchasing the resin and ingredients and doing his own dry blending. The raw materials would cost about 30 cents per pound for a typical good quality compound, and blending costs would run as low as two cents or lower, with a finished formula cost of 32 cents. When this is compared with the cost of such a compound purchased from a supplier at about 35 cents per pound, a real saving can be shown, amounting to about 10 per cent. Capital outlay for suitable dry blending equipment might run from $6,000 to $25,000 and up, depending on size and type.
6. An added benefit is the ability to modify formulas to suit special jobs rather than to make standard formulations do. Inventory is again reduced, because now, instead of needing natural dry blend of several formulations, all that is needed is resin and other raw materials which can be mixed when and as desired.

Some Problems

It would be unfair to say that no problems exist with dry blend as compared with pellets. Since the dry blend resin particles have never been fused or colloided, but are like tiny sponges full of plasticizer, they must be more thoroughly worked than pellets, to complete the compounding process, in addition to the plasticization into a fused single mass of plastic. There is no fisheye, or hard unplasticized resin particle problem, as is the case sometimes in extrusion of PVC, but molding temperature and cycle settings are sometimes more critical to avoid flow marks, particularly with large cross sections or with pieces which are large for the size of the machine. Gate size also becomes more critical with larger pieces.

To help overcome such problems, we have developed a special nozzle insert which acts as a valve or adjustable restriction in the nozzle outlet. As can be seen in Figure 6, it consists of a dispersion disc at the rear of the nozzle, and a ½" landed tapered pin at the front. As the pin is screwed forward, the annular space between the tapered wall and the pin, which has the same taper, decreases. The nozzle thus actually extrudes a tube of plastic into the mold passages, and adds enough working and compounding action to raise the stock temperature 25 to 40°F above the cylinder temperature. In view of facts already noted, the advantage of this is obvious. Lower temperatures can be carried in the cylinder than would otherwise be possible, and the duration of time at the higher nozzle outlet temperature is short before it hits the relatively cool mold.

(Please turn to page 52)

PAINTING and METALLIZING of Plastics

Lloyd E. Parks

Logo, Inc.

THE FIRST STEP in solving a problem is the recognition that a problem exists. Accordingly, a well planned system of inspection should be established for every job. By checking all raw materials and finished products against standards, problems will be recognized when they arise and corrective steps can be taken.

A paint should be specified for a particular job only after it has been examined thoroughly and found to meet the requirements of the application. (The word "paint" is used broadly to cover both lacquers and enamels, as is the general practice in the plastics industry.)

Once production is under way, it is impractical to check each incoming batch of paint for resistance to grease, humidity, stain, abrasion, heat and light. However, these are fundamental properties of the paint film, and it is quite likely that any basic error in formulation affecting them probably will be detected by less extensive inspection.

Such properties as color, gloss, smoothness of film, freedom from craters and pinholes, coverage (including corners and edges), adhesion, tendencies to craze and etch, humidity blush, and the overall appearance are important on every job. These points should be checked before a paint is specified and they should be checked again by inspection of the finished part. A sufficient number of parts should always be inspected to assure shipment of specification merchandise. The amount and type of inspection will depend on the particular job and a statistical study of the operation.

If color is involved, standard color panels or approved finished parts should be in the hands of the paint supplier, the paint receiving department and the product inspection department. Every new batch of paint should be mixed thoroughly and sprayed for color approval before it goes to the paint line. This is a good double check against the supplier and may avoid delays when the paint is needed. However, as will be shown later, this is no guarantee that production parts will always be on color. Problems may develop during the work day. Accordingly, inspectors should always be on guard for color variations.

Visual inspection should also include a check for gloss, uniformity of paint film, coverage, craze lines, etched surface and general appearance. Adhesion is perhaps the best criterion for quality involving points that cannot be observed visually. Spot checks for adhesion should be a part of inspection on every job. Transparent Scotch Tape #600 and Masking Tape #202, supplied by the Minnesota Mining and Manufacturing Company, are widely accepted for the test.

When there is a deviation from standard in raw materials or in the finished product, something has gone wrong and a problem exists. If such errors are allowed to pass through inspection, the problem will go unsolved and sub-standard parts will be shipped with subsequent complaints and rejections from the customer.

Analysis and Solution of Problems

Through proper selection of coatings, it is possible to avoid most problems involving basic film properties, such as resistance to grease, humidity and light. However, paints should be tested for these properties only after the film has thoroughly cured or dried, as the case may be. Tests should be made on the type of plastic to be used in production. Enamels should be baked at the prescribed time and temperature schedule, and lacquers should be allowed to stand at least one to two weeks for complete loss of solvent and hardening of the film before testing. Other properties, though completely satisfactory when the film is applied to good parts under proper conditions, may vary with operating conditions and give rise to problems in production.

Color Variation

Color is an important part of decorating and variation presents serious difficulties in the plastics industry. Manufacturers of automobiles, appliances and other items often purchase the same plastic part from several sources and they expect to get color uniformity. The importance of color control increases when several sources supply different plastic parts, all specified to have the same color and for use on one assembly. The problem becomes more involved when these parts have different types of surfaces—some flat, some curved, some fluted, some diamond shaped, some painted on the first surface and some painted on the second surface. Control in the decorating of various parts of the assembly is further complicated when more than one type of plastic is used or more than one method of painting is required. A number of points important in color control are:

Color Standards: In color shading, like everything else, the last few steps to perfection are the hardest—the most time consuming and most costly. Technically, it is improbable that two batches of a matched color will ever be exactly alike, and usually a trained person can see differences in undertones between batches.

This difficulty in matching production batches exactly makes it advisable to establish production standards with a degree of acceptable variation. The effort expended in attempting to improve a color match past the point which satisfies the average eye brings diminishing returns. Such additional work may produce improvements in color detectable by the trained eye, but these refinements seldom can be justified cost-wise, especially in the production of small batches.

Matched colors vary in several directions. Therefore,

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it is difficult to define accurately the limits of variation allowable in production without complicated and often impractical electronic equipment. Accordingly, a color should be approved as standard and acceptable limits of variation agreed upon as the job gets under way. After producing and shading several batches, the paint supplier will have a good picture of what color accuracy is practical and the user will know if that accuracy is acceptable. Trained quality control and inspection personnel will soon agree on acceptable visual limits of variation in color.

In establishing standards and discussing colors, it is helpful to know that all shades are composed of one or more of the three primary colors—blue, yellow and red. They may be "let down" (diluted or lightened) with white, or they may be "dirtied" (or grayed) by the addition of black or the complementary color. For example, a blue may be too violet (indicating too much red), or too green (indicating too much yellow). Likewise, a yellow may be too green (indicating too much blue), or too orange (indicating too much red), and a red may be too orange (indicating too much yellow), or too violet (indicating too much blue). Any color may be too light or too intense, indicating a variation in the amount of white pigment. Also, any color may be too "dirty" or too "clean" indicating a variation in the amount of black or complementary color present.

In the case of pigmented metallics and other special materials, there may be variations involving the special effects which are commonly called color variations, even though they may not be accurately classified as such.

The keynote to good color control is uniformity in testing raw materials, uniformity of production and careful inspection to catch off-color production parts.

Pigment Separation: In some paint formulations, it is difficult to avoid pigment settling and pigment separation in matched colors. Pigment separation is particularly bad in the case of pigmented metallic colors which contain both finely dispersed non-settling transparent organic pigments and comparatively heavier coarse metallic pigments, such as bronze or aluminum powders. Occasionally, straight metallic colors contain powders that settle at different rates to cause control problems.

Pigment separation may be the source of difficulty when inspection reports a gradual color change as a batch of paint is sprayed. A pigmented metallic blue and a metallic color containing two powders of different specific gravities (aluminum and bronze for color difference), were allowed to settle for one day. In jar 1, the coarse aluminum powder settled to the bottom, leaving the blue pigment in the vehicle above. In jar 2, some of both powders settled, but the bronze settled first and more completely. If parts are sprayed with material poured from the top of these jars without mixing the contents completely, items sprayed from jar 1 will be too blue and items sprayed from jar 2 will give every indication of insufficient metallic powder and a poor color match toward the aluminum side. Successive lots of paint poured from the jars will show a color change. Parts sprayed from jar 1 will become more aluminum rich and parts sprayed from jar 2 will show an increase in metallic powder giving better coverage and varying in color toward bronze.

If such paints are well mixed in the can and transferred to a non-agitated spray tank, the color will be satisfactory only for a while. Then the reverse of this color change may be expected. For example, in the case of the pigmented metallic blue, the first parts sprayed may be on color. However, as aluminum settles and paint is fed to the spray gun from the bottom of the tank, the color will become rich in aluminum and too light in color. This leaves the paint toward the top of the tank too lean in aluminum and too blue in color. As spraying proceeds, the level of paint in the tank falls to a point where parts are again on color. The color will vary toward blue for lack of aluminum as the level continues to fall. A similar situation arises when metallic powders of different settling rates are used.

Improper mixing should always be suspected when there is color variation, and special attention should be given to this point if the paint contains coarse heavy particles such as aluminum and bronze.

Although paint may be mixed by hand stirring, an air driven mixer is highly recommended for mixing in the can. Air driven agitator tanks are recommended for the spray line.

If pigment settling is determined to be the cause of color variation, it may be necessary to open a fresh can of paint, mix it thoroughly, check for color and set up proper procedures to hold the color. It must be remembered that any amount of paint taken from a container which was improperly mixed may leave the remainder of the paint off color. Likewise, when color variation is due to pigment separation, paint remaining in a non-agitated tank may be off color.

Flooding and Application Technique: Flooding involves separation of pigments in the wet paint film and may lead to color variation. By the proper selection of pigments for matched colors and by proper solvent adjustment, it can generally be controlled in both lacquers and enamels containing only milled pigments. However, flooding does occur and can be particularly troublesome in the case of pigmented metallics and those straight metallics which contain powders of different specific gravities.

When flooding is suspected as the cause of color variation, spray techniques should be studied. In general, flooding is most likely in excessively wet films of low viscosity. Within limits, this can be corrected by drying up the spray. However, the degree to which it can be dried up will depend on the amount of high boiling solvent in the paint and in the thinner. Accordingly, the type and amount of thinner used becomes important. The supplier's recommended thinner should always be used unless extreme care is given to selecting an alternate. The supplier's thinning ratio is a good place to start, but this may be modified along with adjustments in gun setting, pressures, distance between gun and part and other conditions.

As a rule of thumb, most metallics, pigmented metallics and other flooding materials handle best when sprayed reasonably dry. However, there is a balance that must be maintained. If they are sprayed too dry, the surface will be rough as a result of dry spray and you will have a new problem of variation in color and in appearance. When the proper spray technique is worked out to get the correct color, it should be set up as standard operating procedure. With a little consideration, these problems can be handled. Again the watchword is "uniformity."

Coverage and Film Thickness: Color variations may be the result of poor coverage, which allows color to show through from the substratum.

A thinner containing chiefly low boiling solvent should be used to reduce the viscosity of the paint for spraying. Such solvents evaporate between the gun and the plastic surface, allowing the paint film to build viscosity so that a film of the thickness desired can be deposited quickly without running. Again, there must be a balance between

too much and too little high boiling thinner. Too little high boiling thinner will cause film rigidity before leveling, giving the appearance of orange peel.

Changing Color of the Substratum: Certain transparent pigments allow the color of the substratum to show through to affect the color of the paint film. However, as long as paint containing such pigments is used on the same substratum and the film thickness is held essentially constant, the color will be uniform. If the color of the substratum is changed, the color of the paint film may also change.

While one answer to such color variation is to avoid transparent pigments or avoid changes in the color of plastic being painted, it is sometimes difficult to match colors with highly opaque pigments. In many instances, transparent covering pigments are perfectly satisfactory as long as the color of the substratum is constant. This type of difficulty emphasizes the importance of matching colors on plastic of the color that is to be used in production. However, there are limitations other than exact color that may determine the type of pigment used. For example the transparent blue has exceptional light stability and it cannot be matched with opaque pigment having equal light stability.

If for some reason it were necessary to paint a large inventory of yellow plastic parts with this transparent light-stable blue, it would be impractical to add enough coats of blue to cover the yellow. A better answer would be to spray a coat of black over yellow to give opacity and then follow with blue to get the royal blue color.

Color Bleeding: Color variation may be the result of dyes or pigments bleeding from the substratum into the paint film when first surfaces are decorated or from a back-up coat into the undercoat in the case of painting a second surface.

The answer to bleeding is to avoid the use of bleeding pigments and bleeding dyes wherever they will come in contact with colors that may be changed by such bleeding. However, batches of parts molded from scrap which contain a bleeding dye may cause trouble if the parts are to be painted light colors. Usually, a coat of black paint over such parts will block the bleeding dye and the parts may then be painted white.

When bleeding is suspected, the paint may be checked by spraying parts known to be free of bleeding dyes or pigments.

Surface Design: It is not always easy to develop colors which will appear the same when viewed from different angles. This point causes difficulty when the design of the substratum varies, either in first or second surface applications. For example, if a flat panel has both smooth and fluted areas on the second surface, the paint on the smooth surface will be viewed at 90° when the panel is held perpendicular to the line of sight, whereas the fluted area may have highlights peculiar to the particular design. Other designs, such as diamonds or points, may appear to have a color different from either the smooth surface or the fluted area, even though the same paint were used.

The answer to color variation resulting from design of surfaces is to make a slight adjustment in the color of the paint to compensate as nearly as possible for the apparent difference. Again, if color is to be critical, it is essential for the paint supplier to have a few molded parts for use in color matching.

First and Second Surface Decorating: Colors matched for use on the first surface of plastic will change in appearance when used on the second surface of clear plastics, and vice versa. This is due in part to the slight coloration of the plastic. However, leafing of pigmented metallics and any flooding of pigments may cause differences beyond the color of the plastic. The answer to these color variations is to match the color for the specific application.

Etching of the Plastic: Color variations caused by etch are usually spotty and irregular over the part and may tend to follow strain lines where active solvent is most likely to attack the plastic. Metallics and pigmented metallics are affected somewhat more by etching than are straight-pigmented colors.

Four panels were painted with the same pigmented metallic blue. When properly thinned for no etch, the color was good when observed as both first and second surface applications. Upon the addition of sufficient active solvent to etch the polystyrene panel severely, the blue color seemed to soak into the plastic leaving the aluminum on top of the paint film. Consequently, the color appears much too dark when viewed through the plastic and much too aluminum-like when viewed as a first surface application.

The solution to etching is strain free parts decorated with paints having a well-balanced combination of solvent and thinner. The paint supplier's recommendations should be followed.

Types of Light Used for Checking Color: Colors reflect differently when exposed to different types of light, and in some cases this variation is appreciable. North daylight is generally accepted as the standard for color matching. However, color matching booths utilizing standardized artificial light are available from a number of sources. Of these, the Macbeth booth is perhaps the most widely used. By some it is accepted as a standard, and by others an alternate for north daylight.

Production colors are usually checked in the plant under commercial fluorescent lamps, so certain precautions are necessary. It is a fact that two colors matched with different pigments may look alike under standard north light, but vary considerably when exposed to certain artificial light. It is therefore important that production standards be sprayed with the same type of paint as that used on the production line. If such is the case, both panels should look alike under production lamps when the match is good in north light.

When there is any question of color variation, both the production part and production standard (sprayed with the same type of paint) should be taken to north daylight or to the standard artificial light source as a double check.

Gloss Variation

Uniformity of gloss is particularly important in painting the first surface. In decorating the second surface, this effect is contributed by the plastic rather than the paint. Even though the paint film may be dead-flat when viewed directly from the reverse side, it will appear glossy when viewed through the plastic.

When a gloss finish is required for the first surface, the formulation with the highest degree of reflectance normally supplied in the proper vehicle can be submitted. However, there are all degrees of flatness, thus, the percent reflectance as determined by a 60° gloss head should be specified for flat and semi-flat finishes. An alternate method is to submit a color panel having the required gloss. In this case, it is desirable to have a flat panel approximately 3" x 4" in order that the percent reflectance can be determined for control records.

Most reflectometers can be equipped with a gloss

(Please turn to page 47)

Effects of Multiaxial Stretching on Crazing and other properties of Transparent Plastics

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PREVIOUS WORK conducted at this laboratory on the effect of multiaxial stretching on properties of polymethyl methacrylate plastic sheet has shown that the resistance to crazing is greatly increased by such orientation (1, 2). In addition, work conducted at the Naval Research Laboratory and at North American Aviation, Inc., has shown that the shattering characteristics are also greatly improved by multiaxial stretching. As a result of this work, development programs are now underway in commercial laboratories for the production of airplane canopies from multiaxially-oriented polymethyl methacrylate.

Several new or modified transparent plastics have recently been produced, offering increased heat resistance and craze resistance. This investigation was undertaken to determine the effects of multiaxial stretching on properties of these polymers, in view of the increased heat resistance they offer.

Materials

The following transparent plastics were studied in this investigation:

a. Lucite HC-222 (MIL-P-5425A): ultraviolet-absorbing heat-resistant grade polymethyl methacrylate, produced by E. I. du Pont de Nemours and Co., Inc. Specimens were tested from two sheets from each of two batches. Each sheet was 36 by 48 inches, of nominal ¼-inch thickness.

b. Plexiglas 55 (MIL-P-8184): modified polymethyl methacrylate produced by the Rohm and Haas Company. Specimens were tested from two sheets from the same batch. Each sheet was originally 48 by 72 inches, and each had been cut into four sheets 24 by 36 inches, of nominal ¼-inch thickness.

c. Gafite: polymethyl alpha-chloroacrylate made by General Aniline and Film Corporation. The sheets received represent experimental material since this polymer is not yet in commercial production. Specimens were tested from two sheets, each 36 by 60 inches and approximately ⅛-inch thick.

d. Resin C: polymethyl alpha-chloroacrylate, produced by Imperial Chemical Industries, Ltd., of England and obtained through the American representatives, Arnold, Hoffman and Co., Inc. The samples received represented experimental material. Specimens were tested from two sheets, each 36 by 48 inches and approximately ¼-inch thick.

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Apparatus and Procedure

Forming

The optimum forming conditions were determined by attempting to stretch pieces of each material after heating at various temperatures for various periods of time. The temperatures did not exceed those at which apparent degradation occurred for each material. The apparatus and the conditions selected are as follows:

Methods. — The equipment used for the multiaxial stretching is described in detail in reference 1. It consists essentially of a flanged cylindrical vessel, approximately 12 inches in diameter, open at the top and having two outlets from the sides, one to vacuum and one to the atmosphere. A 14-inch square sheet of the plastic is heated in an air-circulating oven to the forming temperature, removed, quickly placed over the top of the vessel and clamped in place. The vessel is then evacuated and the plastic drawn into the vessel roughly in the form of a hemisphere. A 10-inch metal cylinder is inserted into the hemisphere, clamped in place and air is admitted into the vessel. The plastic retracts around the inner cylinder, roughly forming a top hat. Test specimens are taken from the 10-inch-diameter flat top of the formed piece. Tests described in reference 1 showed that the degree of stretching was uniform over the area of the flat disk.

Stretching Conditions. — The Lucite HC-222 was heated by suspending the piece to be stretched in the air-circulating oven at 165°C for 30 minutes prior to stretching. The Lucite was stretched 50 percent, 100 percent, and 150 percent, duplicating degrees of stretching obtained previously with polymethyl methacrylate (references 1 and 2).

The Plexiglas 55 was heated at 185°C for 30 minutes prior to stretching and was stretched 45 percent and 85 percent only. The time of heating was varied from 15 minutes to 30 minutes and the temperature from 160°C to 185°C, but it was still not possible to stretch this material more than 85 percent with the equipment used.

The Gafite was heated at 180°C for 30 minutes prior to stretching. There was no visible degradation of the material at this temperature in this period. Thermal de-

gradation of polymethyl alpha-chloroacrylate, as evidenced by bubbling or "pimpling," has been a problem.

The Resin C was heated at 180°C for only 15 minutes before stretching. This abbreviated heating period was used because bubbles developed in some specimens when heated at 180°C for 30 minutes.

Two disks of each degree of stretch were prepared from each of the four sheets of Lucite HC-222 for a total of eight disks for each degree of stretch. For Plexiglas 55, one disk of each degree of stretch was made from each 24- by 36-inch sheet, again making a total of eight disks for each degree of stretch. Two disks of each degree of stretch were prepared from each sheet of Gafite and Resin C for a total of four disks of each degree of stretch for each of these two materials.

Methods of Test

The following tests were conducted on specimens of the unstretched and stretched materials: dimensional stability at elevated temperatures, resistance to surface abrasion, standard tensile, and stress-solvent crazing. These tests were made at 23°C and 50 percent relative humidity after the specimens were stored at these conditions for at least 96 hours, unless otherwise specified.

Dimensional stability. — These tests were conducted to provide thermal stability data and to provide data from which annealing conditions for the stretched materials could be determined. The specimens were small irregular pieces remaining after tensile and abrasion specimens were cut from the formed disks and were approximately 1 by $2\frac{1}{2}$ inches in size. Two lines approximately $1\frac{1}{2}$ inches apart were scribed on the surface of the specimens with a razor blade. The distance between the lines was measured to the nearest hundredth of an inch with a steel scale, graduated in hundredths of an inch, and a magnifying glass. The specimens were then laid on a sheet of plate glass and placed in an air-circulating oven at the test temperature. At the end of 2 hours, the specimens were removed from the oven, allowed to cool for 5 minutes, and the distance between the lines was measured. The specimens were then replaced in the oven and the readings repeated, in most cases, at the end of 6 hours, 1 day, 2 days, and 3 days. Several specimens were measured after they had cooled to room temperature, and no significant difference was found between the measurements made on a specimen while hot and after it had completely cooled. Of each material, four specimens of each degree of stretch were tested at each temperature.

Surface abrasion. — The resistance to surface abrasion was determined for unstretched and stretched materials, following Method 1092.1 of Federal Specification L-P-406b. A Tabor Abraser was used with CS-10 Calibrase wheels and a load of 1000 grams on each wheel. Haze and light transmission measurements were made in accordance with Method 3022 of the above specification, with an integrating-sphere haze meter. These measurements were made after 0, 10, 25, 50, 75, 100, 150, 200, and 250 revolutions of the abraser.

Specimens were cut from the formed disks so that three abrasion specimens were obtained from each pair of disks of the same degree of stretch, that is, two specimens from one disk and one specimen from the other. As a result, 12 specimens were prepared for each degree of stretch for the Lucite and Plexiglas, and six specimens of each degree of stretch for the Gafite and Resin C.

Standard tensile tests. — These tests were made in accordance with Method 1011 of Federal Specification L-P-406b using the Type 1 specimen. The tests were conducted on a 2400-lb. hydraulic universal testing machine. Load-extension data were recorded graphically with a Southwark-Peters extensometer and recorder. A rate of head separation of 0.05 in. min. was used up to 10 percent strain at which point the speed was increased to approximately 0.25 in. min. In some tests, discussed later, the speed of 0.05 in. min. was maintained to failure. In testing the unstretched material, the strain gage was removed at 10 percent strain; the procedure followed for the stretched material is discussed below. Strains greater than 10 percent were followed continuously with and measured with dividers.

In previous tests, use of the strain gage with tensile specimens of stretched material resulted in a tendency toward premature failure, probably caused by the knife edges of the gage. However it was desirable to use the strain gage to obtain load-extension data from which the tensile modulus of elasticity could be calculated. Therefore, half of the specimens of the stretched materials were tested with the strain gage and half were tested without the gage. It was observed that if the gage remained on a specimen of stretched material up to 10 percent strain, the specimen would indent appreciably in the vicinity of the gage springs and fail there. To prevent this, the gage was removed at 2 to 3 percent strain for most specimens; the modulus of elasticity could still be calculated from the load-extension data obtained.

Two standard tensile specimens were obtained from each stretched disk. Thus, 8 stretched specimens of each degree of stretch of the Gafite and Resin C, and 16 stretched specimens of each degree of stretch of the Lucite and Plexiglas were tested. Twice as many unstretched specimens of each material were tested.

Stress-solvent crazing tests. — These tests were conducted on tensile specimens tapering in width from 0.500 inch to 0.333 inch over a 3-inch reduced section. Thus for a given applied load, the stress varied over the length of the specimen from a value S at the maximum cross section to 1.5 S at the minimum. In conducting the test, a predetermined load was applied to the specimen, and a solvent-saturated blotter, backed with a block of polyethylene for rigidity, was held against one face of the specimen for 10 seconds. The load was removed after 30 seconds, and the stress at the point at which crazing terminated was calculated as the threshold stress for stress-solvent crazing. For a given material, this stress depends on the solvent used. Ethylene dichloride was selected for use in these tests as it was desirable to use one solvent for all of the materials and this solvent would cause appreciable crazing on all of the materials to be tested. The specimen distribution was the same as that for the standard tensile tests.

Heat treatment. — Half of the unstretched tensile specimens of each material were subjected to the same heating and rapid cooling cycle as that used in stretching, to determine the effect of this cycle on the tensile properties. In addition, except for the Gafite standard tensile specimens, half of the unheated and half of the heated unstretched tensile specimens as well as half of the stretched tensile specimens were annealed prior to testing. Also, one-third of the abrasion specimens were annealed. The annealing temperature for each material was selected on the basis of the results of the dimensional stability tests and was the maximum temperature at which the stretched material could be heated for 6 hours with less than 5 percent recovery. The temperatures selected were 90°C for Lucite HC-222, 100°C for Plexiglas 55, and 110°C for Gafite and Resin C. The specimens were allowed to cool slowly to room temperature in the oven by turning off the heat and the circulating fan.

Statistical Design

For each test, all of the specimens of a given material were tested prior to testing the next material. The order of testing of the specimens for each material in each kind of test was randomized to minimize bias.

In the tensile tests, for each material, property, and degree of stretching, a simple pooled measure of precision was calculated from the variabilities of the groups of specimens having the various treatments. This standard deviation is listed in the tables of results. The standard error corresponding to any reported average can be calculated by dividing the standard deviation by the square root of the number of specimens involved. The standard error is reported directly for the abrasion results.

Results and Discussion

Dimensional Stability

The results of the dimensional stability test are presented in tables I to IV. In the tests in which there were large decreases in the length of the specimens, most of this decrease occurred in the first two hours. For each material, the higher the degree of stretching, the greater was the recovery at any temperature. Although the differences in thickness in specimens of varying degrees of stretching might affect the extent of recovery after a short heating period, it is doubtful that the thickness differences would affect the degree of recovery after an extended heating period. In comparing the behavior of the various stretched materials at a given temperature, it is observed that the higher the heat distortion point, the lower the degree of recovery. Thus for a given degree of stretch at a given temperature, the Gafite and Resin C, with a heat distortion point of approximately 130°C, recovered the least; the Plexiglas 55, having a heat distortion point of approximately 105°C, recovered more; and the Lucite HC-222, having a heat distortion point of approximately 100°C, recovered the most.

Surface Abrasion

The results of the surface abrasion tests are presented in table V. Values for light transmission and haze, before and after abrasion, are tabulated, as well as values for the slope of the initial portion of the abrasion curve obtained by plotting "Percent Haze" against "Number of Revolutions" of the Taber Abraser. The results obtained for the annealed specimens were similar to those obtained for the unannealed specimens, so the data were pooled. The results indicate that the resistance to abrasion is decreased by multiaxial stretching and there is some indication that this resistance decreases as the degree of stretching increases. There is fair correlation between the value for haze after 250 revolutions and the initial slope of the abrasion curve as a measure of surface abrasion. The Gafite and Resin C were the most abrasion-resistant, the Plexiglas 55 was slightly less resistant, and the Lucite HC-222 was the least resistant. The materials having the greatest abrasion resistance in the unstretched state also had the highest resistance when stretched.

Standard Tensile Tests

Lucite HC-222. — The results of the standard tensile tests on Lucite HC-222 are given in table VI. A series of typical stress-strain diagrams for unstretched and stretched Lucite HC-222 is presented in Figure 1. The shape of the stress-strain curve is not appreciably altered by the stretching.

The heating and cooling cycle used in the stretching operation did not affect the tensile strength of the unstretched material. Annealing resulted in a slight increase in tensile strength of the unstretched and the stretched materials. In addition, there was a slight increase in tensile strength on stretching.

The strain at failure was not affected by the heating or annealing of the unstretched material. The strain at failure was higher for the stretched materials than for the unstretched. It is difficult to make any conclusions as to the variation of strain at failure with degree of stretching, due to the variability of the measure-

Tables of Test Results

TABLE I. DIMENSIONAL STABILITY OF LUCITE HC-222[a]

		Multiaxial Stretch, percent			
		0	50	100	150
Temperature	Time	Decrease in Length, percent			
90° C	2 Hr.	0.0	0.1	0.5	0.8
	6 Hr.	0.0	0.1	0.4	0.9
	1 Day	0.0	0.2	0.7	1.1
	3 Days	0.0	0.2	1.0	1.1
95° C	2 Hr.	0.0	1.2	1.9	2.5
	6 Hr.	0.0	1.3	1.9	2.6
	1 Day	0.0	1.6	2.4	3.0
	3 Days	0.0	1.5	2.6	3.5
100° C	2 Hr.	0.0	8.8	15.6	17.5
	6 Hr.	0.0	12.1	19.1	20.2
	1 Day	0.0	15.0	22.9	25.7
	2 Days	0.0	15.8	24.2	28.0
	3 Days	0.0	16.1	24.6	28.6
	6 Days	0.0	16.4	25.3	29.7
Average Initial Thickness, in.		0.26	0.10	0.06	0.04

a. Each value is the average for 4 specimens.

TABLE II. DIMENSIONAL STABILITY OF PLEXIGLAS 55[a]

		Multiaxial Stretch, percent		
		0	45	85
Temperature	Time	Decrease in Length, percent		
90° C	2 Hr.	0.0	0.4	0.8
	6 Hr.	0.0	0.6	1.0
	1 Day	0.0	0.8	1.0
	2 Days	0.1	1.0	1.1
	3 Days	0.1	0.9	1.1
100° C	2 Hr.	0.0	1.4	1.6
	6 Hr.	0.0	1.3	1.9
	1 Day	0.2	1.5	2.1
	2 Days	0.2	1.5	1.9
	3 Days	0.2	1.5	2.1
110° C	2 Hr.	0.0	10.2	13.0
	6 Hr.	0.0	11.7	14.4
	1 Day	0.2	13.4	15.4
	2 Days	0.3	13.5	15.8
	3 Days	0.3	13.9	16.1
Average Initial Thickness, in.		0.25	0.12	0.07

a. Each value is the average for 4 specimens.

TABLE III. DIMENSIONAL STABILITY OF GAFITE[a]

		Multiaxial Stretch, percent			
		0	50	100	150
Temperature	Time	Decrease in Length, percent			
110° C	2 Hr.	0.0	0.2	0.4	1.8
	6 Hr.	0.0	0.3	0.7	1.8
	1 Day	0.0	0.5	0.8	2.3
	2 Days	0.3	0.6	0.8	2.3
	3 Days	0.0	0.3	1.2	2.0
	4 Days	0.0	0.5	1.2	2.0
120° C	2 Hr.	0.0	1.1	1.6	4.0
	6 Hr.	0.0	1.5	4.1	4.8
	1 Day	0.0	1.9	4.4	5.1
	2 Days	0.0	1.9	4.8	5.2
	3 Days	0.0	1.9	5.0	5.5
130° C	2 Hr.	0.7	21.0	36.7	41.8
	6 Hr.	1.0	27.8	41.7	50.0
	1 Day	2.0	35.0	52.1	61.6
	2 Days	2.3	35.1	52.6	61.8
	3 Days	1.7	35.0	52.5	62.1
Average Initial Thickness, in.		0.11	0.14	0.07	0.05

a. Each value for the stretched material is the average for 4 specimens; for the unstretched material, the average for 2 specimens.

TABLE IV. DIMENSIONAL STABILITY OF RESIN C[a]

		Multiaxial Stretch, percent			
		0	50	100	150
Temperature	Time	Decrease in Length, percent			
110° C	2 Hr.	0.1	0.4	1.0	1.1
	6 Hr.	0.0	0.4	0.8	0.9
	1 Day	0.0	0.6	0.9	1.2
	2 Days	0.0	0.6	0.9	1.2
	3 Days	0.1	0.9	1.1	1.3
120° C	2 Hr.	0.2	2.0	3.2	4.1
	6 Hr.	0.1	2.6	3.6	4.1
	1 Day	0.1	2.7	3.7	4.4
	2 Days	0.1	3.0	4.2	4.6
	3 Days	0.4	3.4	4.2	5.0
130° C	2 Hr.	1.4	32.2	45.0	51.5
	6 Hr.	1.6	34.3	47.8	55.5
	1 Day	1.9	35.8	49.5	58.8
	2 Days	1.6	35.9	50.4	59.1
	3 Days	2.2	36.2	50.8	59.7
Average Initial Thickness, in.		0.27	0.13	0.06	0.04

a. Each value is the average of 4 specimens.

ments. Several specimens of unstretched material were tested without a strain gage to determine if the gage appreciably affected the tensile strength or the strain at failure. No significant differences were found. There was also no significant difference in the values for strain at failure of stretched specimens tested with a gage or without a gage, so these data were pooled.

The secant modulus of elasticity was calculated for the stress range of 0 to 2500 psi. In this range, the load-extension curves were essentially straight. The modulus was not affected by heating or annealing. There was some indication of a slight increase in modulus for the highly stretched material.

The stress and the strain at the onset of crazing for the unstretched material were not significantly affected by the various treatments. This crazing occurred at approximately 90 percent of the tensile strength. None of the specimens of the stretched materials crazed in these tests.

Plexiglas 55. — The results of the standard tensile tests on Plexiglas 55 are presented in table VII. The stress-strain curves obtained for Plexiglas 55 were similar to those for the Lucite HC-222. As in the case of the Lucite, the heating did not affect the tensile strength whereas the annealing resulted in an increase in the tensile strength of the unstretched and the stretched materials. There was also a slight increase in tensile strength for the stretched material compared to the unstretched.

Heating or annealing of the unstretched material or annealing of the stretched material did not affect the strain at failure. Again the strain at failure was much higher for the stretched materials than for the unstretched, but there was no significant variation with degree of stretching.

The modulus of elasticity was not affected by heating or by annealing, but there was some indication of a slight increase in modulus for the more highly stretched material.

The stress at which crazing occurred was increased by annealing the unstretched material. The heating and cooling cycle used in stretching also increased the stress required for crazing. However there was no difference between the annealed specimens and the specimens that were heated and annealed. Crazing of the unstretched material occurred at approximately 95 percent of the tensile strength. None of the stretched specimens crazed.

Gafite. — All of the standard tensile specimens of this material were annealed. The results of the tests are presented in table VIII. The stress-strain curves obtained for Gafite were similar to those for Resin C (Figure 2). There was no significant difference in tensile strength of the annealed and the heated and annealed unstretched specimens. Multiaxial stretching, however, resulted in a significant increase in tensile strength.

The strain at failure of the stretched material was again much greater than that of the unstretched material. The stretched tensile specimens that were tested with a strain gage failed at significantly lower strains than those without a gage. The strain data listed in the table are based on the specimens tested without a gage since these values would represent the true values.

The secant modulus of elasticity was not affected by the heating or by stretching.

The increase in the average value of the stress at which crazing occurs for the heated unstretched specimens over that of the unheated specimens was not statistically significant. The unstretched specimens crazed at

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TABLE V. EFFECT OF MULTIAXIAL STRETCHING ON SURFACE ABRASION OF TRANSPARENT PLASTICS AT 23° C

Material	Multiaxial stretch, percent	Light transmission, percent (Original)	Light transmission, percent (Final[a])	Haze, percent (Original)	Haze, percent (Final[a])	Initial slope of abrasion curve, percent haze per revolution
Lucite HC-222[b]	0	92.1 ± 0.1	88.4 ± 0.2	0.5 ± 0.1	24.7 ± 0.6	0.21
	50	92.0 ± 0.1	87.6 ± 0.2	0.4 ± 0.1	30.4 ± 0.7	0.28
	100[c]	91.9 ± 0.1	87.2 ± 0.2	0.5 ± 0.1	30.6 ± 1.0	0.43
	150	91.8 ± 0.2	86.8 ± 0.2	0.4 ± 0.1	32.0 ± 1.3	0.45
Plexiglas 55[b]	0	91.4 ± 0.1	88.1 ± 0.1	0.5 ± 0.1	21.6 ± 0.1	0.19
	45[d]	91.7 ± 0.1	88.0 ± 0.2	0.6 ± 0.1	25.1 ± 0.6	0.26
	85	91.5 ± 0.1	87.7 ± 0.1	0.6 ± 0.1	26.6 ± 0.8	0.33
Gafite[e]	0	90.0 ± 0.2	87.5 ± 0.1	0.4 ± 0.1	21.6 ± 0.7	0.17
	50	90.6 ± 0.1	86.8 ± 0.2	0.6 ± 0.2	25.4 ± 0.6	0.31
	100	90.5 ± 0.2	87.4 ± 0.2	0.2 ± 0.1	21.8 ± 0.8	0.31
	150[e]	90.6 ± 0.3	86.8 ± 2.8	0.2 ± 0.0	25.2 ± 1.2	0.30
Resin C[e]	0	91.0 ± 0.2	87.9 ± 0.1	0.7 ± 0.1	19.4 ± 0.4	0.14
	50[e]	90.9 ± 0.1	87.4 ± 0.2	0.2 ± 0.1	24.2 ± 0.4	0.26
	100	91.1 ± 0.1	87.0 ± 0.2	0.2 ± 0.1	26.9 ± 1.0	0.30
	150[e]	90.3 ± 0.4	87.1 ± 0.1	0.6 ± 0.1	28.2 ± 2.1	0.30

a. Final measurements were made after 250 revolutions.
b. Average for twelve specimens unless otherwise noted, plus or minus the standard error.
c. Average for six specimens unless otherwise noted, plus or minus the standard error.
d. Average for eleven specimens.
e. Average for five specimens.

TABLE VI. EFFECT OF MULTIAXIAL STRETCHING ON TENSILE AND CRAZING PROPERTIES OF LUCITE HC-222 (POLYMETHYL METHACRYLATE) AT 23° C[a]

Treatment[b]	Tensile strength, (S_m), psi	Strain at failure, percent	Secant modulus[c], 10^5 psi	Stress and strain at onset of crazing: Stress (S_c), psi	Strain, percent	S_c/S_m	Solvent-crazing stress[d], psi
UNSTRETCHED							
None	9,720[e,f]	7.4[e,f]	4.6[e,f,j]	9,070[e,f,j]	1.1[e,f]	0.93	910[e,f,j]
Annealed	10,120	8.6[e]	4.6[e,f,j]	9,140[e]	1.4[e]	0.90	1,450[e,f,j]
Heated	9,510[e]	8.1[e]	4.5[e,f,j]	8,740	1.2[e]	0.92	1,240
Heated + annealed	10,010[e]	8.0[e,f]	4.5[e,f,j]	8,890	1.2[e]	0.89	1,810[e,f,j]
Standard deviation[e]	210	1.2	0.1	310	0.2		140
STRETCHED 50 PERCENT							
Unannealed	9,730	29[b,f]	4.3[i]	Did not craze			1,680[e,f,j]
Annealed	10,110	30[b,f]	4.2[i]	Did not craze			2,210
Standard deviation[e]	200	9	0.1				170
STRETCHED 100 PERCENT							
Unannealed	10,100	17[b,f]	4.7[i]	Did not craze			2,710[e,f,j]
Annealed	10,535	19[g]	4.9[i]	Did not craze			2,150
Standard deviation[e]	140	11	0.2				280
STRETCHED 150 PERCENT							
Unannealed	10,510	16[b,f]	5.0[i]	Did not craze			1,910[e,f,j]
Annealed	10,870	12[i]	5.0[i]	Did not craze			1,580
Standard deviation[e]	210	8	0.1				520

a. The tests were conducted at 23°C and 50 percent relative humidity. Each value is the average for eight specimens unless otherwise noted.
b. Annealed refers to heating at 90°C for 6 hours and cooling slowly. Heated refers to heating at 165°C for 30 minutes followed by rapid cooling in air.
c. The secant modulus of elasticity was calculated for the stress range of 0 to 2500 psi.
d. The solvent-crazing stress is the minimum stress required to cause crazing upon the application of solvent. Ethylene dichloride was the solvent used.
e. The standard deviation was calculated for each property by pooling the variabilities of the groups of specimens having the various treatments.
f. Average of five specimens.
g. Average of six specimens.
h. Average of three specimens.
i. Average of four specimens.
j. Average of seven specimens.

TABLE VII. EFFECT OF MULTIAXIAL STRETCHING ON TENSILE AND CRAZING PROPERTIES OF PLEXIGLAS 55 (MODIFIED POLYMETHYL METHACRYLATE) AT 23°C[a]

Treatment[b]	Tensile strength, (S_m), psi	Strain at failure, percent	Secant modulus[c], 10^5 psi	Stress and strain at onset of crazing: Stress (S_c), psi	Strain, percent	S_c/S_m	Solvent-crazing stress[d], psi
UNSTRETCHED							
None	10,240	6.7	4.8	9,580	1.4	0.94	2,420
Annealed	10,750	6.7	4.6	10,160	4.0	0.95	1,140
Heated	10,190[f]	6.9[f]	4.7	9,810[f]	4.0[f]	0.96	2,470
Heated + annealed	10,715[f]	6.7[f]	4.6	10,030[f]	4.0[f]	0.94	1,220
Standard deviation[e]	80	1.1	0.1	180	0.1		160
STRETCHED 45 PERCENT							
Unannealed	10,660	42[g]	4.8[h]	Did not craze			4,060
Annealed	11,110	43[g]	4.8[h]	Did not craze			5,160
Standard deviation[e]	110	9	0.1				280
STRETCHED 85 PERCENT							
Unannealed	10,940	45[g]	5.1[h]	Did not craze			5,660
Annealed	11,610	57[g]	4.9[h]	Did not craze			6,940
Standard deviation[e]	210	7	0.2				400

a. The tests were conducted at 23°C and 50 percent relative humidity. Each value is the average for eight specimens unless otherwise noted.
b. Annealed refers to heating at 100°C for 6 hours and cooling slowly. Heated refers to heating at 185°C for 30 minutes followed by rapid cooling in air.
c. The secant modulus of elasticity was calculated for the stress range of 0 to 2500 psi.
d. The solvent-crazing stress is the minimum stress required to cause crazing upon the application of solvent. Ethylene dichloride was used in these tests.
e. The standard deviation was calculated for each property by pooling the variabilities of the groups of specimens having the various treatments.
f. Average of seven specimens.
g. Average of six specimens.
h. Average of four specimens.

approximately 85 percent of the tensile strength. Half of the tensile specimens of the material stretched 50 percent crazed at stresses very close to the tensile strength, and half of the specimens broke without crazing. None of the more highly stretched specimens crazed.

Resin C. — The results of the tensile tests of this material are given in Table IX. Typical stress-strain diagrams for unstretched and stretched specimens of this material are presented in Figure 2. Unlike the Lucite and Plexiglas, the unstretched Resin C failed without reaching a yield point. The stretched material, however, reached a yield point before failing, as shown.

Heating or annealing did not affect the tensile strength of the unstretched material. Annealing increased the tensile strength of the stretched material, however. The tensile strength of the stretched material was appreciably higher than that of the unstretched material.

The strain at failure of the stretched material was also higher than that of the unstretched material. The strain at failure appeared to decrease as the degree of stretching increased.

The secant modulus of this material was increased slightly by the multiaxial stretching.

The stress and the strain at which crazing occurred were not affected by heating or annealing the unstretched material, and crazing occurred at approximately 82 percent of the tensile strength. None of the stretched materials crazed in the tensile tests.

Comparison. — The polymethyl alpha-chloroacrylate materials had the highest tensile strengths of the materials tested and showed the largest increases in tensile strength on stretching. This increase is probably due to the more polar nature of the molecule. The tensile strength of the Plexiglas 55 was slightly higher than that of the Lucite HC-222. The strain at failure of the chloroacrylate materials was much less than that of the two methacrylate materials, both in the unstretched and the stretched state. The modulus of elasticity was much higher for the chloroacrylates. The values for the Plexiglas 55 and the Lucite HC-222 were approximately the same. None of the materials showed a large increase in modulus on stretching. Crazing occurred at higher stresses in the chloroacrylate materials than in the methacrylate materials but at a slightly lower percentage of the tensile strength and at a lower strain. The Plexiglas 55 crazed at slightly higher stresses than the Lucite HC-222. In general, the specimens of the stretched materials did not craze in the standard tensile tests.

Stress-Solvent Crazing

Lucite HC-222. — The results of these tests, given in table VI, indicate that both heating and annealing increased the craze resistance of the unstretched Lucite HC-222. The craze resistance of the unstretched material was approximately doubled by heating and annealing and was increased approximately 50 percent by annealing alone. The resistance to stress-solvent crazing was increased by stretching, and increased as the degree of stretching increased. Annealing increased the threshold stress of the 50-percent-stretched material, but the variability of the measurements masked any effects of annealing for the more highly stretched materials. It is interesting to note that the threshold stress for the unstretched material after heating and annealing is slightly greater than that for the unannealed 50-percent-stretched material.

Plexiglas 55. — The values for threshold stress for stress-solvent crazing are presented in Table VII. The crazing resistance of the unstretched material was increased approximately 25 percent by annealing. There

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TABLE VIII. EFFECT OF MULTIAXIAL STRETCHING ON TENSILE AND CRAZING PROPERTIES OF LUCITE (POLYMETHYL ALPHA-CHLOROACRYLATE) AT 23°C[a]

Treatment[b]	Tensile strength, (Sm), psi	Strain at failure, percent	Secant modulus[c], 10^5 psi	Stress and strain at onset of crazing: Stress (Sc), psi	Strain, percent	Sc/Sm	Solvent-crazing stress[d], psi
UNSTRETCHED							
None	--	--	--	--	--	--	2,510[e]
Annealed	16,060	1.0	7.7	13,510[f]	2.1[f]	0.84	2,920[h]
Heated - annealed	16,200	1.0	7.4	13,180	2.6	0.86	--
Standard deviation[e]	1,750	0.4	0.5	410	0.2		120
STRETCHED 50 PERCENT							
Unannealed	--	--	--	--	--	--	4,960
Annealed	19,730	17[g]	7.8[g]	18,770[i]	4.6[h]		6,820
Standard deviation[e]	150	8	0.8	160	0.5		100
STRETCHED 100 PERCENT							
Unannealed	--	--	--	--	--	--	8,940
Annealed	19,550	11[g]	7.6[g]	Did not craze			11,110
Standard deviation[e]	210	2	0.4				1,170
STRETCHED 150 PERCENT							
Unannealed	--	--	--	--	--	--	15,120[j]
Annealed	19,170	12[g]	7.8[g]	Did not craze			17,110[k]
Standard deviation[e]	510	1	0.7				1,520

a. The tests were conducted at 23°C and 50 percent relative humidity. Each value is the average for eight specimens unless otherwise noted.
b. Annealed refers to heating at 110°C for 6 hours and cooling slowly. Heated refers to heating at 180°C for 30 minutes followed by rapid cooling in air.
c. The secant modulus of elasticity was calculated for the stress range of 0 to 2500 psi.
d. The solvent-crazing stress is the minimum stress required to cause crazing upon the application of solvent. Ethylene dichloride was used in these tests.
e. The standard deviation was calculated for each property by pooling the variabilities of the groups of specimens having the various treatments.
f. Average of seven specimens.
g. Average of four specimens.
h. Average of three specimens.
i. Four specimens crazed at the average stress and strain listed. Four specimens did not craze.
j. Result for one specimen. Two specimens did not craze at an average stress of 17,460 psi.
k. Average for two specimens. Two specimens did not craze at an average stress of 17,290 psi.

TABLE IX. EFFECT OF MULTIAXIAL STRETCHING ON TENSILE AND CRAZING PROPERTIES OF RESIN C (POLYMETHYL ALPHA-CHLOROACRYLATE) AT 23°C[a]

Treatment[b]	Tensile strength, (Sm), psi	Strain at failure, percent	Secant modulus[c], 10^5 psi	Stress and strain at onset of crazing: Stress (Sc), psi	Strain, percent	Sc/Sm	Solvent-crazing stress[d], psi
UNSTRETCHED							
None	16,170	1.1	7.4	13,100	2.2	0.82	2,850
Annealed	16,430	1.1	7.5[f]	13,350	2.2[f]	0.81	3,410
Heated	16,090	1.2	7.1	13,300	2.1	0.83	3,910
Heated - annealed	15,910	1.0[f]	7.3[f]	13,240	2.1[f]	0.84	4,050
Standard deviation[e]	500	0.1	0.1	440	0.1		110
STRETCHED 50 PERCENT							
Unannealed	17,720	21[f]	7.6[f]	Did not craze			6,430
Annealed	18,780	17[f]	7.6[f]	Did not craze			7,500
Standard deviation[e]	410	1	0.2				150
STRETCHED 100 PERCENT							
Unannealed	18,310	12[g]	8.2[g]	Did not craze			12,950
Annealed	19,190	10[g]	7.9[g]	Did not craze			13,620
Standard deviation[e]	120	4	0.5				300
STRETCHED 150 PERCENT							
Unannealed	18,610	9[g]	8.0[g]	Did not craze			18,140
Annealed	19,340[f]	--	8.1[g]	Did not craze			>17,820
Standard deviation[e]	90	1	0.6				470

a. The tests were conducted at 23°C and 50 percent relative humidity. Each value is the average for four specimens unless otherwise noted.
b. Annealed refers to heating at 110°C for 6 hours and cooling slowly. Heated refers to heating at 180°C for 15 minutes followed by rapid cooling in air.
c. The secant modulus of elasticity was calculated for the stress range of 0 to 2500 psi.
d. The solvent-crazing stress is the minimum stress required to cause crazing upon the application of solvent. Ethylene dichloride was used in these tests.
e. The standard deviation was calculated for each property by pooling the variabilities of the groups of specimens having the various treatments.
f. Average of three specimens.
g. Average of two specimens.

TABLE X. TENSILE PROPERTIES OF MULTIAXIALLY STRETCHED ACRYLIC PLASTICS[a]

Material	Multiaxial stretch, percent	Number of specimens	True stress at failure, psi	Strain at failure, percent	Tensile strength, psi	Stress at failure, psi
Lucite HC-222	50	5	15,330	68	9,970	9,640
	100	5	14,430	50	10,230	9,900
	150	4	11,820	16	10,640	10,600
Plexiglas 55	45	4	15,500	51	11,070	9,720
	85	4	14,520	18	11,120	10,560

a. These data were obtained in tests conducted at a testing speed of 0.05 in./min to failure. True stress is based on cross-sectional area at failure.

Stress-Strain Diagrams of Three Plastics

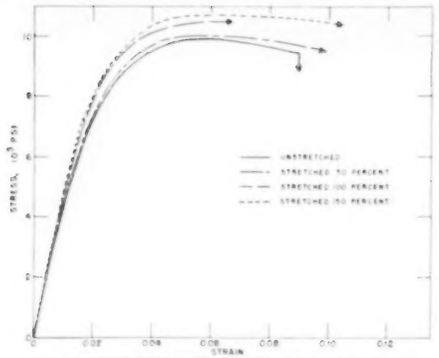

FIGURE 1. STRESS-STRAIN DIAGRAMS OF POLYMETHYL METHACRYLATE

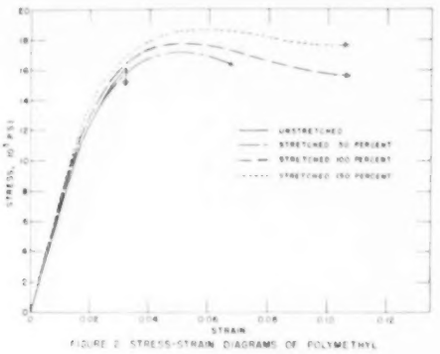

FIGURE 2. STRESS-STRAIN DIAGRAMS OF POLYMETHYL ALPHA CHLOROACRYLATE

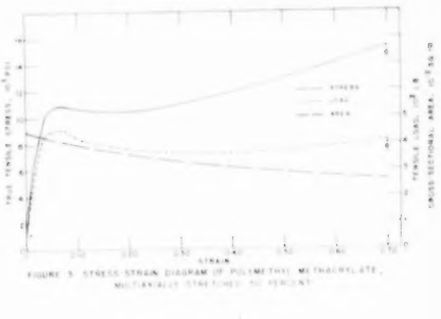

FIGURE 3. STRESS-STRAIN DIAGRAM OF POLYMETHYL METHACRYLATE, METHACRYLATE STRETCHED 50 PERCENT

was also a slight increase in craze resistance on heating the unstretched material. The threshold stress for stress-solvent crazing again increased as the degree of stretching increased and the craze resistance of the stretched material was increased by annealing.

Gafite. — The results obtained for this material are listed in table VIII. The specimens that were heated and then cooled rapidly to simulate the stretching cycle warped slightly when cooled. As a result, the values for threshold crazing stress varied, depending on whether the solvent was applied to the concave face or the convex face. The average threshold stress for the concave faces was 2690 psi and for the convex faces was 4460 psi. Thus any slight curvature introduced into the sheets produces a marked effect on the crazing behavior. For the unstretched specimens that were not heated, the resistance to crazing was increased by annealing. The threshold stress for stress-solvent crazing increased greatly as the degree of stretching increased. In fact, half of the 150-percent-stretched specimens did not craze at stresses greater than 90 percent of the tensile strength. Annealing markedly improved the craze resistance of the stretched materials.

Resin C. — The data for this material are presented in table IX. The heating cycle increased the threshold stress for stress-solvent crazing appreciably for the unstretched material. Annealing increased the craze resistance of the unstretched specimens that were not heated but had little effect on the specimens that were heated. Resistance to crazing increased greatly with the stretching and none of the 150-percent-stretched specimens crazed at stresses of approximately 95 percent of the tensile strength. Annealing increased the craze resistance of the 50- and the 150-percent-stretched materials.

Comparison. — Multiaxial stretching markedly increased the threshold stress for stress-solvent crazing for all of the materials tested. This threshold stress increased for each material as the degree of stretching increased. The Lucite HC-222 showed the least resistance to stress-solvent crazing with ethylene dichloride. This was true for the unstretched state as well as for the stretched. The Plexiglas 55 was next in craze resistance and was considerably better than Lucite HC-222. In fact, the 45-percent-stretched Plexiglas 55 was more craze resistant than the 150-percent-stretched Lucite HC-222. The chloroacrylate materials were by far the most resistant to stress-solvent crazing with ethylene dichloride. The threshold stress for the heated unstretched Resin C was approximately the same as that for the 150-percent-stretched Lucite HC-222, and the threshold stress for the 50-percent-stretched Resin C was greater than that for the 85-percent-stretched Plexiglas 55. For these four transparent plastics, those which had the higher craze resistance in the unstretched state also had the higher craze resistance in the stretched state.

Effect of Annealing and of Heating

The effects of heating and of annealing of the test specimens were not completely consistent for all of the materials tested. For the unstretched materials, the heating and rapid cooling did not significantly affect the tensile strength of any of the materials. Annealing the unstretched specimens increased the tensile strength of the heated and unheated Lucite HC-222 and Plexiglas 55. Annealing the stretched specimens resulted in increased tensile strengths in every case.

The stress at which crazing occurred in the standard tensile tests was not significantly affected by annealing or by the heating cycle except for the Plexiglas 55. In this case, annealing increased the stress required as did the heating cycle alone but there was no difference between the annealed specimens and the specimens that were heated and annealed.

The threshold stress for stress-solvent crazing was increased by heating and by annealing the unstretched specimens of all four materials. The threshold stress was also increased by annealing the stretched specimens of all four materials except Lucite HC-222. The threshold stress for the 50-percent-stretched Lucite HC-222 specimens was increased by annealing but there was no significant effect for the more highly stretched specimens of this material.

Annealing did not affect the surface abrasion resistance of the stretched materials. It was thought that the annealing might relieve some of the residual stresses in the stretched material, and thus increase the abrasion resistance to a degree comparable to that of the unstretched material. The results show that this did not occur.

Annealing of the stretched specimens resulted in some recovery of the stretching, corresponding to the values reported in tables I to IV. As a result of this decrease in degree of stretching, decreased resistance to crazing and decreased tensile strength might be expected. However the effect of annealing was large enough to compensate for this decreased degree of stretching. Further studies will be made of this behavior.

Tensile Tests at Low Testing Speeds

In the previous investigations conducted on stretched polymethyl methacrylate, very little increase in tensile strength was observed for the stretched materials over

the unstretched. However, there was a marked decrease in the cross section of tensile specimens of the stretched material prior to failure because of the high extensions, whereas the unstretched material broke at low strains with little change in cross section. Thus the true stress at high extensions was much greater for the stretched specimens than that based on the original area.

Several tests were conducted in this investigation on specimens of stretched Lucite HC-222 and Plexiglas 55 without increasing the speed of testing when the strain reached 10 percent. A speed of 0.05 in./min. was used up to failure. At this low speed, measurements could be made of the width and thickness of the specimen at various extensions. From these data, the true stress at various strains could be calculated. Since most of the specimens of the stretched chloroacrylate materials broke at strains of 20 percent or less, no measurements of this type were made on these specimens.

In these tests on Lucite HC-222 and Plexiglas 55, the width and thickness of the test specimen were measured with micrometer calipers to the nearest thousandth of an inch, starting at 10 percent strain and continuing at intervals of 10 percent strain until failure. The cross-sectional area at failure was obtained by extrapolation. The load was observed at each reading.

The results obtained in these tests are given in table X. Typical true stress vs. strain diagrams for the stretched Lucite HC-222 and Plexiglas 55 are shown in Figures 3 to 6. The results show that the true stress at the yield point is approximately 10 percent greater than the tensile strength which is based on the original area. The materials with the highest tensile strength did not have the highest true stress at failure. The 50-percent-stretched materials, which elongated the most and thus decreased the most in area, had the highest values for true stress at failure. That is, for each material, the true stress at failure was related to the strain at failure. The true stress at failure varied from approximately 25 percent to 50 percent greater than the tensile strength.

From the measurements made in the above tests of the changes in dimensions of the tensile specimens of the stretched materials, it was possible to calculate values for Poisson's ratio. This is the ratio of the lateral strain to the axial strain. These values were calculated from changes in width and in thickness, compared to changes in length for each specimen, starting at 10 percent axial strain and measured at intervals of 10 percent strain to failure.

The results show that Poisson's ratio is approximately 0.4 to 0.5 at 10 percent axial strain and decreases to approximately 0.3 to 0.4 as the elongation increases. The reported value for Poisson's ratio for unstretched Plexiglas II is 0.35. It will be necessary to refine the technique used in making these measurements on the stretched material to establish quantitative relationships.

Stang, Greenspan, and Newman (reference 3) showed that for 24 ST aluminum alloy sheet, 24 SRT aluminum alloy, and chrome-molybdenum steel, Poisson's ratio increases, reaches a maximum, and then decreases as the axial strain increases. This behavior was shown to be qualitatively the same as for an ideal case of no plastic dilatation in an isotropic material.

Appearance of Crazed Specimens

The stress crazing of Lucite HC-222 was apparent as a rather uniform blushing of the cast surfaces, common for polymethyl methacrylate as shown in Figure 7. The crazing of Plexiglas 55 although not nearly as uniform nor as dense also appeared on the surface only. The stress crazing of the polymethyl alpha-chloroacrylate specimens was rather uniform and quite dense and was apparent in the interior of the specimens as well as on the surface. This was true for both the Gafite and the Resin C. The effect shown in Figure 7 is typical of that observed for all the chloroacrylate specimens which had been subjected to each of the heating and annealing treatments. Further study will be made of the nature of this crazing.

The stress-solvent crazed specimens were similar in appearance to those tested in the previous investigations. The craze cracks of the stretched materials were finer and more numerous than for the unstretched materials. For each material, the cracks became finer as the degree of stretching increased.

Fracture Behavior

The fracture surfaces of the unstretched Lucite HC-222 and Plexiglas 55 specimens were flat and relatively smooth and were perpendicular to the cast faces. A smooth mirror-like area was apparent on each fracture surface and was probably the point at which fracture initiated. This behavior has been discussed in previous reports (references 1 and 2). The fracture surfaces of the polymethyl alpha-chloroacrylate specimens were very rough and uneven and usually slightly curved. Numerous small pieces broke out of the fracture surfaces of the chloroacrylate specimens at failure. It was very difficult to detect a mirrorlike area on most of these specimens. Examples of the fracture surfaces are shown in Figure 8.

Secondary fractures occurred in numerous chloroacrylate tensile specimens. Most of these fractures occurred in the portion of the specimen in the tensile grips and are probably related to the stresses caused by the grips. However, in some cases, multiple fractures occurred in the reduced portion of the chloroacrylate tensile specimens. A few of the Plexiglas 55 specimens had secondary fractures in the tensile grips but there were none in the

Stress-Strain Diagrams of Three Plastics

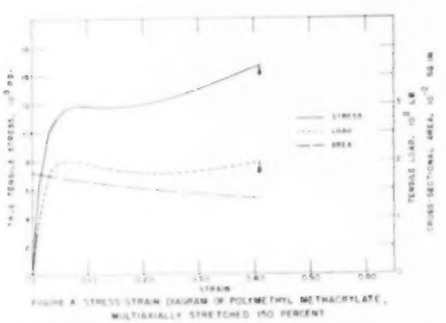

FIGURE 4. STRESS-STRAIN DIAGRAM OF POLYMETHYL METHACRYLATE, MULTIAXIALLY STRETCHED 150 PERCENT

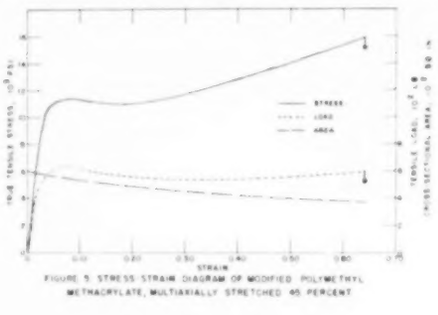

FIGURE 5. STRESS-STRAIN DIAGRAM OF MODIFIED POLYMETHYL METHACRYLATE, MULTIAXIALLY STRETCHED 45 PERCENT

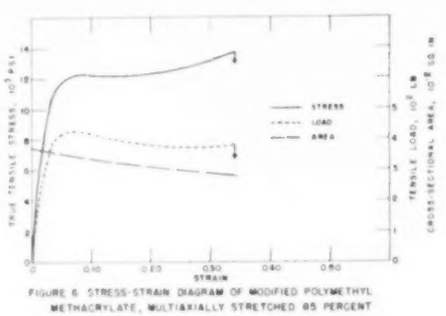

FIGURE 6. STRESS-STRAIN DIAGRAM OF MODIFIED POLYMETHYL METHACRYLATE, MULTIAXIALLY STRETCHED 85 PERCENT

Lucite HC-222 specimens. Miklowitz (reference 4) has reported secondary fractures for Plexiglas I-A and attributes this secondary failure "to the superposition of the longitudinal strain and the resultant flexural strain, which together total more than the original static tensile fracture strain."

The fracture surfaces of the stretched materials showed the same laminar structure observed in the previous investigations of polymethyl methacrylate (references 1 and 2). This structure is probably due to the orientation of the molecule chains in layers parallel to the plane of the sheet. The higher the degree of stretching, the more apparent was this layerlike orientation. In many cases, a triangular-shaped piece split out of a tensile specimen of stretched material at the point of failure. This phenomenon, shown in Figure 8, probably represents a combination of tensile failure and shear failure. Further studies will be made of this behavior.

Conclusions

Tests were conducted to determine the effects of multiaxial stretching on various properties of several new transparent plastics. As a result of this study, the following conclusions can be drawn:

1. Polymethyl alpha chloroacrylate can be multiaxially stretched at least 150 percent, whereas Plexiglas 55 (modified polymethyl methacrylate) cannot be stretched more than 85 percent with the apparatus used.

2. The stretched materials will recover gradually if heated to a sufficiently high temperature. The higher the heat distortion point of the unstretched material, the lower is the extent of recovery of the stretched material at any given temperature within the range investigated. For any material, the higher the degree of stretching, the greater is the extent of recovery at a given temperature. Most of the recovery occurs in the first two hours.

3. Multiaxial stretching causes the following general effects on the transparent plastics studied:

(a) A decrease in the resistance to surface abrasion;

(b) A slight increase in tensile strength;

(c) A large increase in strain at failure;

(d) Little effect on the tensile modulus of elasticity;

(e) Large increases in resistance to stress crazing and to stress-solvent crazing. This resistance increases with increasing degree of stretching.

4. Annealing increases the tensile strength of the stretched materials slightly and has the same effect for some of the unstretched materials. The resistance of both unstretched and stretched materials to stress-solvent crazing is usually increased markedly by annealing. However, the stress crazing behavior of the unstretched materials is not affected by annealing in most cases. Resistance of the stretched materials to surface abrasion is not affected by annealing.

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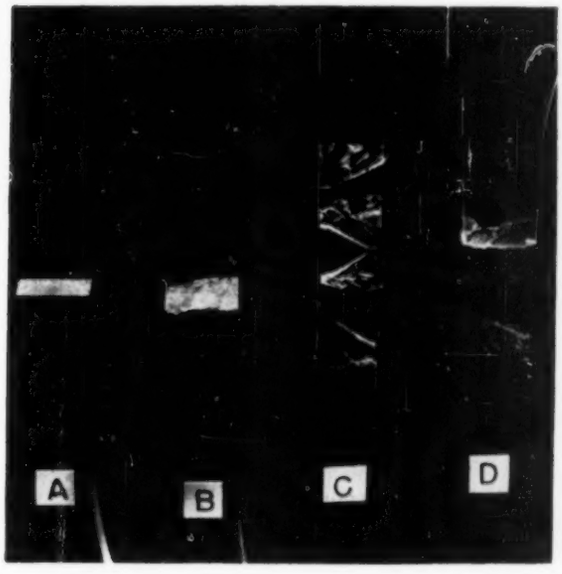
← *Left*

Right →

Figure 8.—Fracture surface of unstretched and stretched polymethyl methacrylate and polymethyl alpha-chloroacrylate: (A) unstretched polymethyl methacrylate; (B) unstretched polymethyl alpha-chloroacrylate; (C) modified polymethyl methacrylate stretched 45 percent; (D) polymethyl alpha-chloroacrylate stretched 100 percent. Note third piece (turned over) broken out of specimen C. Specimen D broke into two pieces only (top piece is turned over).

Figure 7.—Stress crazed specimens of polymethyl methacrylate (A) and polymethyl alpha-chloroacrylate (B). Note internal crazing apparent in side view (second specimen) of polymethyl alpha-chloroacrylate but not in side view (second specimen) of polymethyl methacrylate.



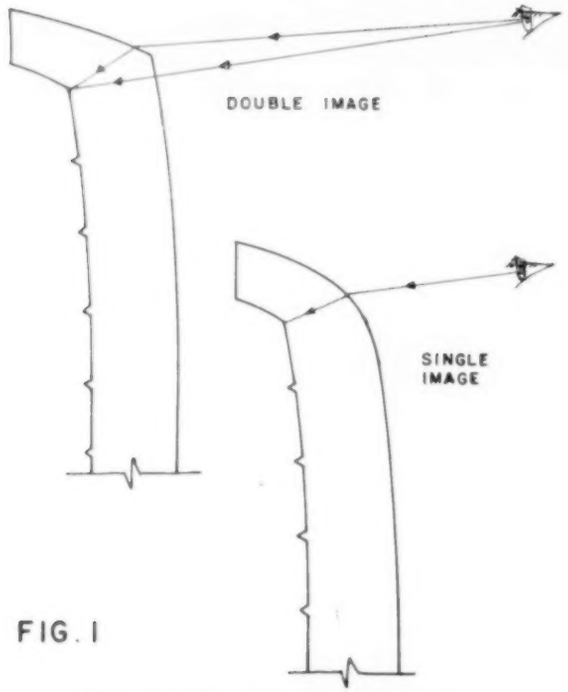


FIG. 1

Changes of Plane Cause Double Images

Designing With Transparent

Alfred M. Blumenfeld
Rohm and Haas Co.

THE EXPERIENCE THAT designers and engineers have inherited and developed with conventional opaque materials, such as metals, ceramics, wood and fiber, have enabled them to make a relatively easy transition to design of opaque plastic products. The play of light and shadow on the external surfaces, the integral color, the blind fasteners on the hidden rear surfaces have, if anything, made their task a simpler one, which no doubt accounts for the strong competitive position of plastics today and their evolution from "ersatz" or replacement applications to ones where they are unquestionably the best and sometimes only answer to the problem.

This same pattern does not apply to transparent plastics. When called upon to design such parts, designers generally find themselves faced with a great many unforeseen problems. The design heritage passed down from pressed and cut glass, gem stones, and transparent sheet materials does not go far enough in techniques or imagination to give them the background to design the clear molded parts for new appliances, automobiles and other products.

No longer can they think only in terms of reflected light, for now the rays enter the material itself and refraction begins to play tricks with both light rays and vision. The back surface becomes more important than the front one in many cases and concealment of fasteners and the related components behind the part bedevil the unwary. Since instinct and common sense most often lead them in the direct opposite direction, their only alternative is to explore the causes of these troubles, master them, and begin to take advantage of the functional, esthetic, and merchandising values of this exciting new group of materials, the transparent plastic molding compounds.

The logical source for them to turn to for guidance is the material manufacturer. To offset the despair of those who fail to achieve their intended design effects and turn to other more familiar materials, some materials manufacturers have gone to great lengths to explore the problems, find the answers, publish educational literature, and offer direct consulting help on specific problems to the individual designer, engineer, or product manufacturer.

Basic Design Considerations

1. Avoid the use of a flat plane whenever possible. Even the slightest crown or curvature will go a long way toward overcoming erratic first surface reflections resulting from sink marks, faulty mold finishing or other causes. Crisp design is still possible without absolutely straight lines across surfaces or around the peripheral sides. This is even more important where large areas of the second surface are to be vacuum metalized. A flat mirrored surface shows every flaw at one time. A very slightly crowned mirrored surface reflects only a band of light and helps to conceal minor flaws of imperfect optically flat surfaces, contamination particles, or uneven clear undercoat paint film application. This simple rule should substantially reduce the rejection rate due to factors that very few of us can entirely control.

2. Avoid sudden changes in external surface form. (Figure 1) Sudden changes of plane create lensatic or prismatic distortions of vision through the transparent part. Especially around the edges of second surface decorated parts this can lead to double images which are unwarranted, annoying and detract from the beauty of the part. External corners should be as generously and gradually radiused as the designer can make them. Only by treating the exterior in as "soft" and organic a way as possible can distortions be kept to a minimum and the true integrity of the design of the second surface be realized. The second surface is the place for the designer to express himself in terms of changes of plane, crispness or softness of motifs, break-up of the overall area into contrasts of texture, color, and form. If he would take the attitude that he is designing the top surface of an opaque die casting or stamping with applied colors and then covering it with a protective transparent layer

ent Plastics

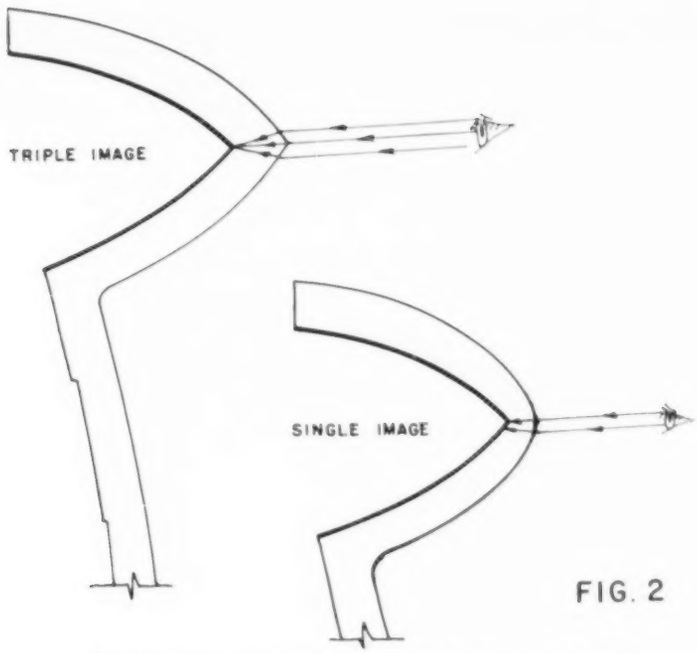


FIG. 2

Keeping Design "Crisp" Can Result in Double or Triple Images.

.xxx" thick which will have a smooth top surface easy to wipe clean and having no places to catch dirt and no corners to chip, he would virtually guarantee getting the results he is seeking. In short, **style the second surface,** not the first surface.

One specific problem in this regard that deserves mention is the incorporation of metalized bezels or frames integrally with transparent lenses, windows or decorative escutcheons (Figure 2). More and more we are finding designers using this device for automotive parking lights, speedometer dial covers, appliance dials and medallions, and the like. When they design a sharp, crisp cross section to the bezel which is to be second surface metalized, they invariably repeat the sharp peak on the first surface to "keep it crisp." The result is a double or triple image of the sharp peak by complex refraction of the sight lines and a view edgewise down through the clear material itself, which has come to be known as the "icing effect." While there is no easy pat answer to both of these aberrations, ninety percent of the trouble can be eliminated by following the rule noted above—design the second surface, keep the first surface soft and generously radiused.

3. Dial markings or other copy on transparent see-through parts are generally more durable and legible when applied to the second surface. Whether hot stamped, silk-screened, wiped-in, or mask sprayed, such indicia tend to show up better whether edgelighted or viewed under front ambient light. Again the avoidance of perfectly flat surfaces on the exterior reduces the annoyance of first surface reflections. Dials should be canted forward at the top if feasible or curved concavely to further reduce such reflections. On edgelighted dials a dark background color is helpful but the background color should be applied to a separate background material and not be applied to the second surface of the clear plastic. Dark colors applied to the surface of a transparent material absorb light rays which are intended to be internally reflected in a flux across the part and hamper the even illumination of indicia farthest from the light source.

4. Cross sections of second surface decorative surfaces should be in shallow relief. In parts of thick section, such as automotive horn buttons, where it is desired to locate the rear surface decorative elements deeply into the part, the top surfaces of the decorative areas should still be kept shallow in crown or faceting with deep returning sidewalls of ample draft to insure ease of mold release and application of decorative coatings (Figure 3).

Specifically on lettering where a vacuum metalized letter with 45° beveled surfaces is desired, the mirror bright surfaces at such an extreme angle will cause internal reflections laterally through the part. The results are annoying reflections of adjacent letters or motifs or worse, loss of brilliance and sparkle in materials with high edge color. The remedy is a relatively shallow pitch to the beveled surfaces of 15° to 25°. This will usually look like 45° but will permit the reflective letter to pick up ambient light coming in through areas of the first surface in close proximity to the point where the visual sight line enters and avoid internal reflection or loss of brilliance in materials with high color. The same theory applies even more so where a half round metalized letter stroke is desired. The chances for success will be markedly improved if the top surface of the letter is constructed as an arc intercepting the three points of the 15° beveled top letter we just mentioned.

5. Be wary of internal reflections of colors from remote areas (Figure 4). It is sometimes possible to design a central theme motif in such deep relief and without regard to the rules noted above that the sight line will enter the first surface, reflect off the design theme at a wide angle, strike the underside of the first surface at a point so far removed laterally that the angle of the

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Design Examples

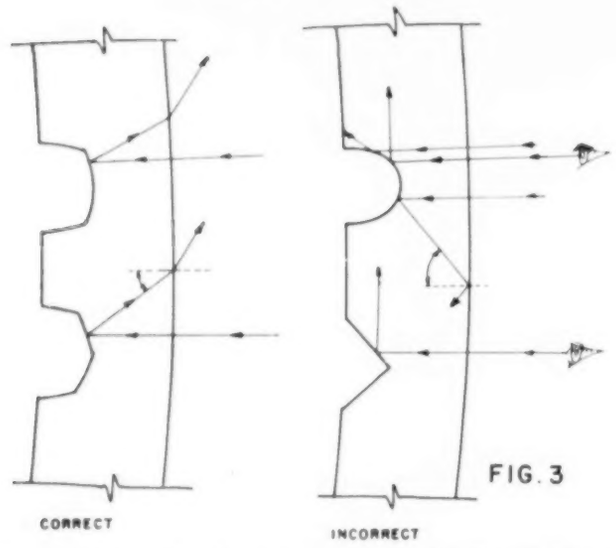

Fig. 3 Bright second surface at an extreme angle will cause internal reflections.

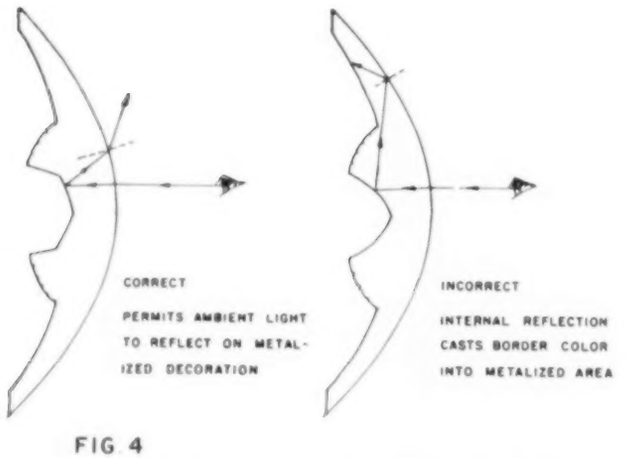
CORRECT
PERMITS AMBIENT LIGHT TO REFLECT ON METALIZED DECORATION
INCORRECT
INTERNAL REFLECTION CASTS BORDER COLOR INTO METALIZED AREA
FIG. 4

Fig. 4. Color splotches from second surface result from incorrect design.

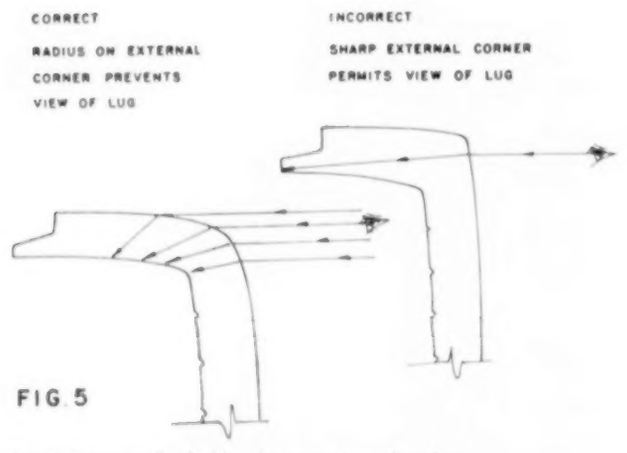

Fig. 5. Lug can be hidden by curvature of surface.

rays (generally more than 40° from the normal) can not emerge into air and are internally reflected to the second surface at a point near the outer edge of the part where a vivid border color may be picked up. This results in the central motif, which might have been intended to be bright silver, to have a large ugly splotch of red on it for no apparent rhyme or reason. This is more prevalent in large thick parts or parts with deep convex or concave curvatures. Bright lettering colors can show up as ghosts on the light background at points several inches away and generally completely baffle all concerned. Bulletins on behavior of light and sight rays in transparent materials, refraction tables and simple refraction plotting devices are available and can help alleviate this "mirage" effect if used intelligently.

6. Provide paint stops by a change in plane between adjacent color areas. Forethought applied to this problem can result in tangible savings to the customer in lowered rejection rates and cost of spray masks. Another helpful note is to avoid carrying a background texture of deep relief, such as lines, fluting, or waffle patterns directly into the side wall return of a letter stroke or design motif of a different color. Counter bore the side wall of the letter or motif to the depth of the background texture and allow the background color to cut off at the straight line edge of this counter bore.

It is very difficult and costly to attempt to mask and spray an all over pattern of dots across a part of large size, such as a band across a refrigerator, freezer, air conditioner, or TV set. The plastic materials tend to expand and contract with variations in temperature and humidity to a degree that renders precise control of mask to part relationship nearly impossible. Most molders and decorators are aware of this, but I would like to emphasize it for the designers. If it is desired to use the same color in more than one area of such a large part, it is probably preferable to attempt to confine this color to "zones" and use multiple masks.

While we are mentioning masks and spray painting, we should bring up the problem of deep set lettering with flat tops and crisp sharp corners, a favorite of the automotive designers. When transparent colors for gold and other metallic effects are sprayed into such a letter the result is generally a pile up of paint in the center of the flat stroke and little in the sharp corners where the letter face meets the return. This is due to the difficulty of spraying deep letters and the air cushion that forms in a sharp inside corner. There are three remedies, all important. Provide as much draft to the sidewall returns as possible and then add a degree or two more. Put a minimum radius on the inside corners, no matter how small. One can still achieve the visual effect of crispness he seeks with a reasonable break of the corners and probably do better than bright plating over cast metal or stampings. Finally, put a minimum crown across the flat face of the letter stroke to offset the "hollow ground" effect you will get from an uneven build-up of transparent paint in the center of the letter stroke.

Concealment Of Attachment Devices

In opaque materials the attachment problem can usually be left as an after-thought; integral lugs, bosses, tapped holes in the back, or many other methods present little trouble. With transparent materials the problem must generally be considered right from the start if concealment is to be successfully achieved. Where metal bezels

(Please turn to page 54)

Epoxy Resins . . . Electrical Applications

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IF ONE WERE TO dissect almost any piece of electrical equipment, one would be struck by the relatively small volume of insulating material in the structure. Since for most applications in ordinary temperature ranges, insulation is to a large degree synonymous with plastics, it would apparently be fair to say that volume-wise, and therefore dollar-wise, plastics can play no enormous role in the industry. If the total volume of plastics utilization in electrical products is so small, how then can one justify a serious interest in epoxy resins, which form only a part of the plastics picture?

Insulation Is Important

Actually, this minor role is more apparent than real. Even in the simplest cases, electric current can be made to travel in a required path only if it is confined, and this confinement largely becomes the role of plastics. In other cases (as for example in capacitors) where the technical requirements are more complex or severe, the confining material must possess quite special characteristics since it not only serves to keep the current in the proper place, but plays an active role in determining the action and/or specifications of the equipment itself. Hence all insulating materials are significant, and therefore the epoxy resins with their immense range of possibilities, (and in some cases unique characteristics), amply justify a great deal of interest and technical work. This is recognized by the major electrical organizations, all of whom devote considerable time, talent and funds to the study and application of epoxy resins.

The electrical industry is faced with a very interesting set of inter-related problems. It is not usually sufficient to choose an insulating material purely on the basis of its resistance to the voltage intended, and the mechanical aspects of fabrication. Because electrical stress can and does exert a direct chemical effect on the dielectric, and because the effects of time and temperature cannot be ignored either electrically, chemically, or mechanically, it is necessary that some little attention be paid to the chemistry of a proposed insulating material. Further, since electrical equipment does occasionally use plastics materials in applications other than strictly electrical ones, such items as adhesion, weathering, and a great many others inevitably enter the picture. It seems appropriate, therefore, to introduce any discussion of epoxy resins with a brief picture of their chemical nature and how this affects some of the properties mentioned.

Epoxy Chemistry

The fundamental reaction which leads to the formation of the most important commercial epoxy resins is shown in Figure 1. By suitable control of the alkalinity and the amount of epichlorohydrin used, it is possible to control the molecular weight of the product. In this way, a wide range of basic resins is made available to the industry.

The utilization of the fundamental material is possible because it may be reacted to form cross-linked products. Both acid- and base- catalyzed polymerizations are common, but it must be understood that in either case the finished products contain the cross-linker as an integral portion of the structure, and that therefore, the reaction is much more nearly akin to condensation than to catalysis in the most rigorous sense of the term. Acidic hardening or catalysis is illustrated in Figure 2.

Here it is obvious that cross-linking can occur, but, since the product contains free hydroxyl groups, a second reaction can take place at these points with evolution of water. The presence of water would lead to undesirable properties in the finished product. It is preferred to employ acid anhydrides as examplified in Figure 3.

In a typical case, for example, with phthalic anhydride, the reaction proceeds through the formation of a half-ester as a first step. This half-ester then reacts with the epoxide groups to yield a polymer which is not only an ester but still contains a hydroxyl group available for further reaction. In this way the polymerization proceeds until complete cross-linking has resulted.

Basic catalysis is shown in Figure 4.

It will be seen that the general picture is not unlike that of acid catalysis, and leads to polymers in much the same way. However it is true that not only primary but secondary and even tertiary amines can cure epoxy resins. Therefore there must exist also a simple catalytic

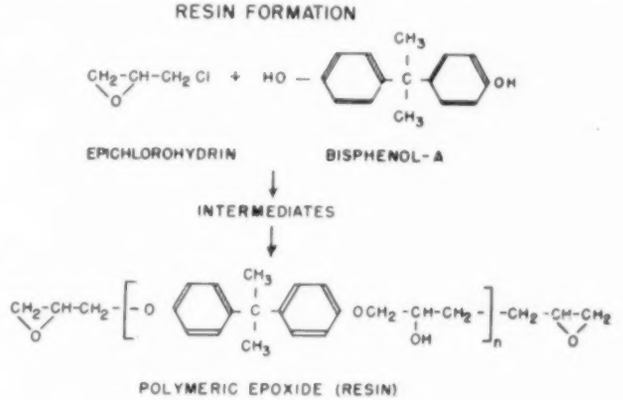

FIGURE 1

This paper was presented at the 12th SPE Conference.

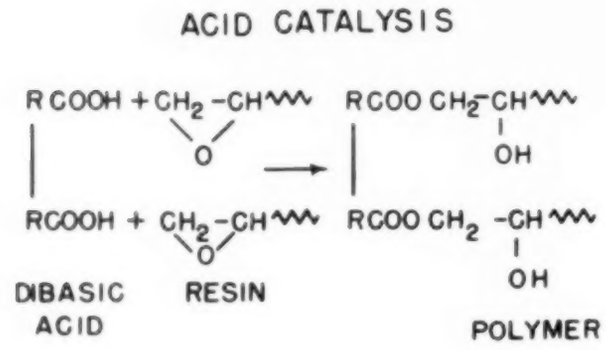

FIGURE 2

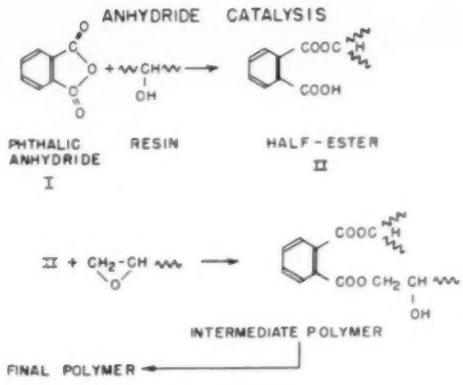

FIGURE 3

polymerization which one might describe as a general base-catalyzed type. Most of the applications of epoxy resins depend on one or other of these two general mechanisms, although very often the acidic or basic groups are supplied by a more complex molecule specifically prepared to provide certain modifications and properties. We will return to this question later.

The reaction with bases is in general more rapid than that of acids. For this reason a great many formulations based upon the use of such catalysts have appeared. The reason for this preference is probably to be found in the high degree of reactivity of amine-catalyzed systems, which enables the user to formulate relatively fast-curing materials, molding products, and the like. It is interesting to note that in exercising a preference for amines, one must make a choice between convenience and speed of operation, on the one hand, and electrical properties on the other. Amine-catalyzed systems contain some degree of polar functionality associated with the nitrogen atom. The result is that amine-catalyzed systems show higher losses (high dissipation factor and power factor) than do well-cured acidic systems. Incidentally, it must be assumed in treating any of the principal properties, that the cure has been complete. Formo and Bolstad (1) have shown that suitable post-curing of a standard epoxy resin can reduce the average molecular weight between cross-links from 4,000 to 1,100, which indicates rather considerable chemical changes, that, if not prevented, can cause a great deal of randomness in the apparent properties as measured. Even in such cases as those in which a relatively high heat-distortion point can be attained, as in the case of metaphenylenediamine hardener, the electricals tend to drop off as the temperature rises. Presumably this is due to the fact that greater freedom of internal movement is permitted in the softened material at the elevated temperature. This observation on the electrical characteristics versus chemical constitution brings us face to face with the question of formulation for use: What chemical steps can be taken in order to arrive at specific ranges of properties as demanded by the electrical engineer?

It is possible to list a number of such properties and to discuss how formulation is related thereto. With today's emphasis on higher operating temperatures in electrical equipment, one of the first questions asked of the chemist is that he supply materials with high heat-distortion points, minimum loss at elevated temperatures, maximum thermal stability over reasonable lifetimes at elevated temperatures, and freedom from ionic materials which, at elevated temperatures particularly, will lower the resistance of the insulating material. At the same time, various degrees of flexibility are demanded, along with freedom from flow, adhesiveness, and resistance to common corrosion in the presence of water, acids, etc.

To treat all of the property questions would involve a disproportionate amount of time. We will attempt, therefore, to discuss only a few important representative cases, including power factor and degradation.

Acid-hardened systems, which contain little polar functionality, show lower power factors at elevated temperatures than do amine-hardened materials, as has been

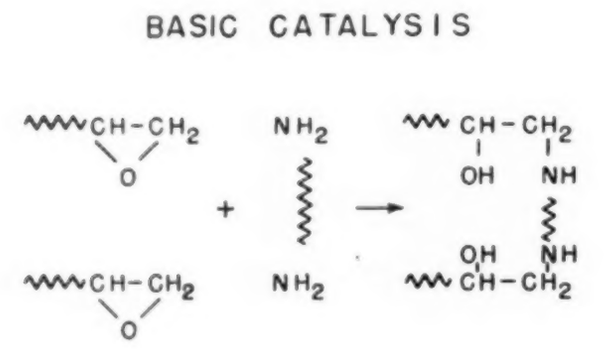

FIGURE 4

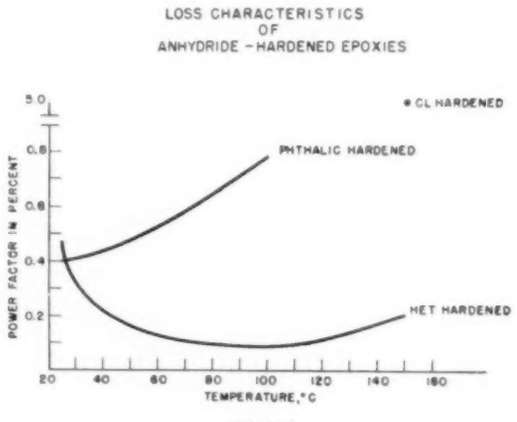

FIGURE 5

said. It is interesting to note that a still further reduction of electrical losses can be accomplished if inter-molecular bonding can be increased, even if in only a secondary way.

When chlorendic anhydride (Figure 5) is used in place of phthalic anhydride as a hardener for a standard epoxy resin, not only is the heat-distortion point raised to a level approaching 180°C, but the dissipation losses are kept to an unusually low figure which reaches a minimum of only 0.1% at 100°C. and about 0.2% at 150°C.

In this connection it is interesting to contrast the effect of amine-type hardeners in a similar system: an epoxy resin hardened with metaphenylenediamine shows a power factor of about 5% at 150°C, presumably due to the greater polarity associated with the nitrogen atoms. Figure 5 compares anhydride and amine-hardened epoxies in this respect.

Resistance to elevated temperatures includes several important factors; the material must possess maximum dimensional stability and resistance toward mechanical deformation at the temperature under consideration, it must not deteriorate chemically to give off noxious or corrosive products, and its electrical resistivity must remain at an adequate level for a long time, otherwise small leakage currents ultimately build up a sufficient temperature to wreck the insulation and consequently the apparatus.

It is probably unnecessary to elaborate on the effect of increasing degree of reactivity of the hardener upon the heat-distortion point of an epoxy resin. Active cross-linkers containing the relatively inflexible phenyl group, whether amine or acid in type, can both yield products whose heat-distortion points approach 170 or 180°C. Examples may be found in cures with methaphenylenediamine and with "Chlorendic" or "HET" anhydride. The names "Chlorendic" and "HET" have been devised in a very laudable effort to get around the use of either "1, 4, 5, 6, 7, 7,-hexachlorodicyclo-(2, 2, 1)-5-heptene-2,3,-dicarboxylic anhydride", or "hexachloroendomethylenetetrahydrophthalic anhydride".

Since it would appear that both electrical and mechanical properties can be improved by the use of certain specific hardeners, it might be of some interest to examine the effect of aging at elevated temperatures, upon materials hardened with some of these agents.

Effect of Chlorine

It has been common experience in the electrical industry that any substance which easily liberates chlorine, will give rise to manifold troubles including corrosion, leakage, and failure. How are we to reconcile this body of prior experience with any proposed use of chlorinated hardeners, even though their short-time electrical and mechanical properties be entirely satisfactory? Here again, the chemistry of the material comes to our aid. It is a widely observed fact that a single chlorine atom attached to a methylene group in an ordinary carbon chain, is comparatively easily removed by heat or hydrolysis, particularly under an electrical stress. This has proved to be a limiting factor on the temperature of application of such extremely useful materials as polyvinyl chloride. However, it is true that a chlorine atom attached to an unsaturated carbon or a tertiary carbon is considerably more stable than an aliphatic chlorine, and it is true also that in the structure of "HET" or "Chlorendic" anhydride, shown in Figure 6, the chlorines attached to the bridge carbon atom show the relatively high degree of stability associated usually with chlorines attached to an unsaturated carbon atom. This is reflected

"HET" OR "CHLORENDIC" ANHYDRIDE

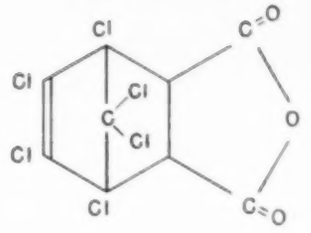

FIGURE 6

in some of the stability measurements which are presented in Table 1.

The stability comparison is made on the basis of weight loss, with full appreciation of the fact that weight loss is not the only measure which can be applied. Still, since a loss in weight may be regarded very largely as an evolution of corrosive and conducting material in this particular instance, it is felt that such a simplification is justified. It is clear that even at these elevated temperatures, which are actually beyond any range in which a chlorinated epoxy is seriously proposed for use, there is a considerable difference of stability in favor of the epoxy hardened with the chlorinated hardener, as contrasted with polyvinyl chloride. We must note, however, that the statement cannot be carried over into hardening with tetrachlorophthalic anhydride, which shows a degree of stability intermediate between that of the chlorendic type and that of polyvinyl chloride. It might be expected that the effect of moisture vapor on the insulation should be much more severe than that of dry air. But it is found that the chlorine attached to this particular ring is more stable to moisture also, and that, as a result, epoxies reacted with these hardeners undergo a much less rapid and serious degradation than does polyvinyl chloride or a tetrachlorophthalate polyester. Thus, when a phthalic-cured epoxy, a "HET"-cured epoxy, and polyvinyl chloride were heated for seven days at 135°C in sealed tubes containing copper and moist air, the amount of scale formed on the copper was about one-tenth as great over HET-epoxy as over polyvinyl chloride. (2).

In connection with thermal properties, it might be pointed out that the fire-retardancy of the chlorine-containing type of epoxy resin is very good, as might be predicted from the known behavior of other highly-chlorinated plastics, such as polyvinyl chloride.

Control of mechanical properties is usually exerted through the use of fillers, but other means are also at hand. For example, if a more flexible type of cured epoxy polymer is required, the linkage between the epoxy chains may be altered. Thus, a polyester containing a small

Table I

Stability of Epoxies and PVC

	160°C Residual Weights (%)			180°C Residual Weights (%)		
DAYS	HET	PA	PVC	HET	PA	PVC
0	100	100	100	100	100	100
6	—	—	—	—	—	71
8	100	99	92	—	—	—
12	—	—	—	99	97	—
13	100	99	90	—	—	—

excess of acid groups can be used in place of an acid or anhydride. If this polyester hardener is long enough or branched enough, a more flexible product results. For instance, glycol maleate reacted with an epoxy resin yields a flexible coating suitable for use with fibrous tapes in making wire insulation.

A particularly well-known property of the epoxy family is its good adhesion to metals and other materials. This property has led to the use of epoxies in a great many adhesive applications. Of these, we might mention only two, illustrating the diverse ways in which this valuable property can be put to use.

Epoxy Adhesives

In the assembly of a stack of laminations to form the magnetic portion of a motor, a transformer, or a choke, it is almost always necessary to fasten the individual sheets of steel very tightly together, both to achieve the maximum magnetic efficiency in the minimum possible volume, and to form a rigid mechanical unit. Commonly, this assembly has been performed by riveting, bolting, or welding. Each of these systems has its merits, and all are standard. In the past few years it has become possible through the use of adhesive epoxy formulations, to assemble stacks rigidly and uniformly by merely coating the metal with the adhesive, pressing under light pressures, and curing. By proper formulation, high strength, adequate insulation resistance, and good thermal stability have all been realized. Also, since the stacks are firmly anchored to the very edge, an adhered stack is inherently a quiet stack. While the application of the adhered stack is not widespread today, it is used in critical cases where none of the other methods is completely satisfactory. An interesting fact comes to light in this connection, in that the imposition of an external stress upon a magnetic material usually results in an increase in the energy loss due to development of heat within the stack. It has been found that the most rigid epoxy resins cured to their maximum rigidity, can cause as much as 10 to 12% increase in loss. Since this is undesirable, it would seem likely that less rigid materials would take up the stresses within themselves rather than impose them upon the metal. (3)

This has been found to be the case, and moderately flexible epoxies have been found to cause only very minor increases in loss. Ordinarily, it is necessary to insulate between successive layers of magnetic material. This is not difficult to do with an appropriately designed system, in which a solid stand-off or solid separator is used in addition to the adhesive.

It is interesting to note that exactly the opposite requirement is sometimes met, in which the adhesive must not be an insulator, but must rather show the minimum possible resistance. In this case too, epoxy adhesives have shown themselves to be useful. (4) Experimental pairs of dissimilar metals have been prepared by welding, and by adhesion with a standard epoxy adhesive under relatively low pressure ranging from 60 to 500 psi. The resistance between the metals in the welded units was 1.28 ohms while comparable epoxy units measured 0.856 ohms. It was found, too, that the resistance values were essentially independent of bonding pressure in the pressure range mentioned. This is not to say that epoxy bonding is necessarily better than welding, but it is obvious that the resistances are comparable.

An interesting application of an adhesive epoxy system is given by Marty, Davies, and Franklin who have printed resistors directly upon small ceramic plates for printed circuitry applications. (5). In this case, formulations of an epoxy resin, urea-formaldehyde, solvents, and carbon, were made up as inks. These were then injection molded against the surface of the base-plate material in a small mold with a cavity ranging up to 5 mils thick. After cure, the resistors formed in this way showed moderately good resistance to high relative humidity, increasing in resistance from 10 to 15% after 250 hours' exposure at 95% relative humidity. The change was reversed on drying. Coating further reduced the effect of moisture to less than 5%. As might be expected, the amount and type of carbon filler had a considerable effect on the resistance, so that suitable control could easily be exercised by proper choice of constituents. In the particular instance cited, no ordinary curing agent or hardener was used; instead the urea-formaldehyde constituent reacted with the epoxy to cure the entire system.

One of the more promising applications for epoxy materials is as a binder for mica products and similar structures, particularly for use at elevated temperatures. Both flake and crushed mica may be bonded with epoxy materials to form either flexible or rigid plates, tapes, or tubes. Segment plate, for example, (which is the name applied to a solid, rigid board used to separate the metallic bars of a commutator) is now available with a dielectric strength of 1,500 volts per mil and an arc resistance of 180 seconds (6). In themselves, these figures would not be remarkable, but they are coupled with a very low degree of thermal degradation and virtual freedom from sliding or oozing even under loads of 25,000 psi for 5 minutes at 240°C. Thus, a much more stable structure can be realized through the use of epoxy binders.

Since epoxy resins wet glass particularly well, it has been an obvious step to prepare good reinforced structures with epoxy binders. (7, 8).

Table II

Typical Properties of some Epoxy-Glass Laminates (30 - 35% Resin)

Resin Molecular Weight	350-420	350-420	900-1,000
Curing Agent	Diethylene triamine	Metapheny-lene diamine	Dicyan-diamide
Cure	30 min. at 240°F	15 min. at 300°F + 1 hr. at 400°F	30 min. at 330°F
Flexural Strength (psi)	62,800	.73,300	84,500
Flexural Modulus (psi x 10^6)	2.9	3.3	3.7

Table III

Electrical Properties of some Typical Epoxy-Glass Laminates

	60	1 K	100 K
Dielectric Constant	5.25	5.20	5.10
Dissipation Factor	0.0043	0.0049	0.011
Volume Resistivity (ohms)	1 x 10^{16}	——	——
Dielectric Strength (v/m)	——	700	——

Such materials are fairly common on the market, and are used for both mechanical and electrical purposes, as exemplified by the well-known boards upon which circuits are being printed. The circuit-board application shows a high degree of resistance to moisture and soldering temperatures, and very good mechanical properties. An interesting variation of the reinforced structure is afforded by a large coil form, 24" diameter, 60" long, and ¼" thick. (9). This was wound up from well-dried glass roving and epoxy resin, catalyzed with methaphenylenediamine without the use of any woven structures whatever. This ¼" thick material has passed a 65KV test without puncture. The strength of this type of structure is quite adequate, being about 20,000 psi in the axial direction and 80,000 psi in the circumferential.

The application which seems to have captured the imagination to the largest extent is that of embedment and encapsulation of components and circuits. It would be interesting to consider why these materials virtually dominate the field of embedment and encapsulation today.

A look at the requirements for a typical casting will provide the answer.

Table IV

Characteristics of a Casting Material

1. Good adhesion
2. Low shrinkage on cure and during life
3. Maximum insulation resistance
4. Adequate mechanical properties
5. Adequate chemical and moisture resistance
6. Low pouring viscosity
7. Near-room-temperature cure
8. Coefficient of thermal expansion like that of common metals
9. Stability of properties vs. heat and time

The epoxies are inherently excellent adhesives (tensile shear strengths of 4,000 psi on aluminum are readily attainable. (10). Shrinkage during cure is exceptionally low; values of 0.25%-1.25% for filled and 0.5%-2.5% for unfilled compositions having been reported. (11). Good electrical properties come with the material: resistivities the order of 10^{16} ohm-cm. place epoxies in the highest bracket. The base resin, moreover, may be compounded to provide a wide range system of materials for many embedment applications. The processing and mechanical properties of epoxies are too well-known to require elaboration.

Some discussion of several successful applications will illustrate the versatility of epoxies. A transformer manufacturer was faced with the problem of replacing the dipcoating of a 3-phase, 60-cycle, high voltage transformer with a process which would cut down on production time (7 days per piece) and yet improve the quality of the product. (12). Since the transformer weighed 95 lbs. and measured 12" x 7" x 6", the problem was one of considerable dimension.

A heavily-loaded epoxy resin was used. This was necessary to bring down the coefficient of thermal expansion of the resin, to approach that of the transformer core and coil, and thereby to increase the thermal shock-resistance of the unit. An alternate method to accomplish the same end result would be the introduction of an elastomer into the epoxy system.

The unit was thoroughly dried before casting, to prevent moisture-inhibition of the cure. Evaporation of the catalyst during cure, with subsequent undercure at the surface, was eliminated by pouring a low-melting wax over the liquid resin. When cure was complete, the molten wax was poured off. A two-hour vacuum-impregnation cycle was used. This more efficient impregnation permitted better realization of the excellent electrical properties of the epoxy, by removing voids which might lead to localized corona with resultant heating and degradation of the neighboring resin. The cure time, incidentally, was held to 16 hours at 150°F.

While this transformer was designed to pass MIL-T-27 Grade 2 Class A, all units passed Grade 1 Class A requirements. The objectives were met: improved quality and appearance, and a 7:1 reduction in production time.

Heat Dissipation

In some casting applications, the dissipation of heat and the crushing of fragile components by the resin must be considered. (13). This was true in the embedment of sections of a six-channel amplifier demodulator. Here the heat was transferred outside of the resin casting by placing vacuum tubes in metal castings in contact with a heat-dissipating surface. The crushing of fragile assemblies was eliminated by coating them with a resiliant "shield" of vinyl plastisol.

In another application (14) it was found that when potted to improve resistance to moisture and dirt, a locomotive governor rheostat operated 40°C cooler. This should be reflected in longer life.

High exothermy, especially in a large mass of resin, may be reduced by choice of hardener and filler. An improved design may also cut down on the amount of resin needed. Recent epoxy-polyamide formulations, dip coated, have complied with MIL-T-27, Grade 1 Class A. (15) Expanded epoxy compounds, using either blowing agents or gas-filled phenolic spheres represent the latest contributions to the ever expanding field of epoxy embedments.

Epoxy molding compounds have recently been described. (1) These formulations retain the inherently favorable properties of epoxy resins, using mold times ranging from 3 to 5 minutes. These materials depend on the reaction of an epoxy resin with methylene dianiline, using catechol as an accelerator to reduce the molding cycle. Various synthetic fibers and mineral fillers were used in the formulations. High fluidity at the molding temperature facilitates the molding of thin sections and the inclusion of fragile inserts.

These developments represent a significant contribution to the elimination of one of the major shortcomings of epoxy resins, namely, the extended cure times.

A whole field of new electrical applications should result, since the production of a high-grade electrical product containing various inserts is a common problem in the industry.

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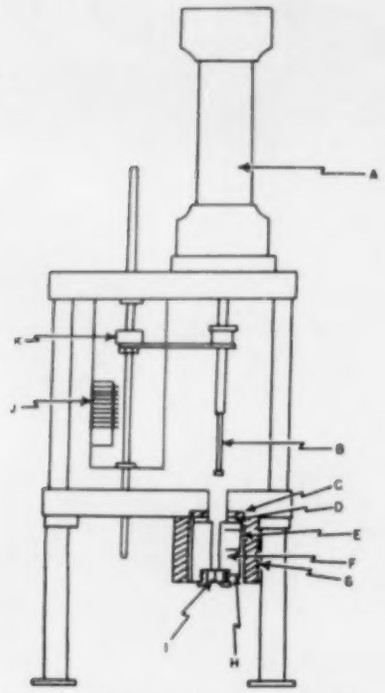

Fig. 1—Schematic drawing of capillary rheometer.

Melt Fracture—Extrudate Roughness In Plastics Extrusion

J. P. Tordella
E. I. du Pont de Nemours and Co., Inc.

THE OBJECT OF MELT extrusion of thermoplastics is the continuous production of useful products of given, uniform cross sections. In gasketing, coated wire, pipe, tubing, film, sheeting, and monofil, the optimum is perfect regularity at a desired thickness. A small amount of irregularity may require added thickness for adequate physical properties. Large irregularities may render the product unsatisfactory. In this paper causes of various types of irregularity are discussed. Melt fracture which may result in severe irregularity is discussed in considerable detail.

Experimental

Most of the work reported in this paper was done in a small, ram extruder or capillary rheometer which is shown schematically in Fig. 1. It consisted of an electrically heated (E) metal cylinder (F) within which operated a piston (B) which was driven by a pneumatic cylinder (A). The bore of the rheometer cylinder was 0.375 in. and its length 3½ in. At the bottom of the bore, dies (I) were held by a threaded gland. Volume rates of flow were calculated from the rate of piston motion. The rate measuring device consisted of a cam (K) which was driven by the piston past several thin metal contactors (J). The contactors operated electric timers which measured the time of contact of the leaves with the cam. A potentiometric recorder-controller was used to control the temperature using the bottom thermocouple (H) of the three in the rheometer cylinder. The cylinder was insulated (G) against heat losses to the air and isolated from the frame by means of a disc heater (D) and an asbestos composition disc (C).

The advantages of this instrument over commercial extrusion equipment for flow studies were several. (1) Temperature of and pressure on the sample could be controlled and measured accurately. (2) Only small samples were required. (3) Dies were inexpensive and readily changeable. (4) With proper attention to the flow variables, shear rate and shear stress, flow data obtained with this instrument apply with surprising exactness to full scale commercial equipment. In addition to the experiments in the rheometer, experiments were also conducted in two-inch diameter extruders (by others in the laboratory) to check the conclusions.

Causes Of Roughness

Rough extrudates and those whose shapes do not conform to the cross section of the openings of the extrusion dies may result from any of several causes. Among these are presence of volatile material and gel particles in the polymer, extrusion swelling, poor die finish, die geometry, and melt fracture. These are discussed, in order, and methods of their control are given.

It is well known that volatile constituents such as water may show up as crater-like depressions from burst surface bubbles and that gel particles may show up as small bumps. Elimination of such defects obviously requires elimination of the volatiles and gel.

The dimensions of the cross section of extruded plastics always tend to be larger than the corresponding dimensions of the extrusion dies. This "ballooning" or extrusion swelling does not usually cause roughness. However, it may result in considerable distortion of the extruded shape relative to that of the die. The amount of extrusion swelling may be reduced by any of the following: drawing the melt, raising the temperature, lengthening the die, and lowering the throughput.

Rough interior surfaces extrusion dies may result in rough extrudate surfaces. Tool marks or scratches in a die land in the direction of flow tend to cause marks or streaks along the length of the product. However, a mirror finish on die lands may not be necessary. Sand blasted surfaces and those on which the tool marks are transverse to the flow direction appear to have little effect on the finish of the extrudate surface.

Uneven flow across the face of a die may result in irregular extrudates. With capillaries, this usually is no problem. With slits and annuli, it is necessary to main-

tain both the gap size and temperature constant along the face of the die opening. Failure to do so may result in irregular sheet or film. Indeed, it is sometimes necessary to minimize[1] and/or compensate for pressure drop down the channel feeding a slit or annulus to produce uniform flow rates across the face of the die.

In the extrusion of shapes more complex than monofil or sheet and film, it may not be possible to produce uniform flow rate across the face of the die. In a die of variable cross section, the flow rate through the large-area midsection will be much larger than that through the constricted edges. Either of two types of irregularity may occur. First, if the discharge rate of the extruded shape approaches the linear velocity of the polymer issuing through the edges, than the material in the middle which is flowing at a much higher linear rate will either swell excessively or buckle. Buckling may produce a large amplitude, very objectionable waved surface as shown in Fig. 2. Second if the discharge rate of the stream approaches that of the open, center section of the die, then the polymer at the edges will be melt drawn. Under these conditions melt fracture, which is discussed below, may result in a ragged edge with tears transverse to the extrusion direction.

Melt Fracture, A Critical Stress Phenomenon

Melt fracture differs from the above causes of extrudate irregularity in that it occurs only at and above a critical stress or extrusion pressure. Melt fracture[2] occurs in the inlets of extrusion dies. Small cracks or fractures initiate and propagate in die inlets at and above critical pressures. Results[3] of melt fracture in extrusion of "Lucite" 140 acryiic resin through a capillary are shown in Fig. 3. At low extrusion pressures or shear stresses, the extrudates were smooth and regular (see top specimen in Fig. 3), and the flow rates low. As the pressure was increased the flow rate and the diameter of the extrudates increased. At and above a critical pressure the extrudates become increasingly irregular. The second specimen in Fig. 3 was obtained at the critical stress. Although it does not show in the photograph, melt fracture had occurred and this specimen was irregular. There was a light, spiral groove running down its surface. In the next four specimens results of melt fracture were more severe; the irregularity progressed from a plainly visible, spiral groove to what appeared to be a series of short segments. The last of these specimens, which was broken in handling, contained many small, internal fissures.

The irregular shapes of the extrudates result from "elastic memory". After emerging from the die, the extrudates tend to regain the configuration they had before extrusion. Fracture, which is an irreversible process, makes the recovered shape asymmetric; spirals, "zig-zags", and segments result.

The characteristic shape of fractured extrudates from slit dies is shown in Fig. 4 along with a piece of coated wire. Instead of the spiral obtained with a capillary, slits often produce film or sheeting with waves perpen-

[1] *J. F. Carley, J. App. Phys., 25, 1118 (1954).*
[2] *J. P. Tordella, "Fracture in Viscoelastic Liquids under Shear Stress," to be published.*
[3] *This type of irregularity has also been ascribed to post-extrusion buckling: R. S. Spencer and R. E. Dillon, J. Coll. Sci., 4, 241 (1949); R. S. Spencer, J. Poly. Sci. 5, 591 (1950); R. S. Spencer, Polystyrene (Reinhold Publishing Corp., New York, 1952) P. 582; R. S. Spencer, Proceedings of the Second International Congress of Rheology (Academic Press Inc., Publishers, New York, 1954) p. 20.*

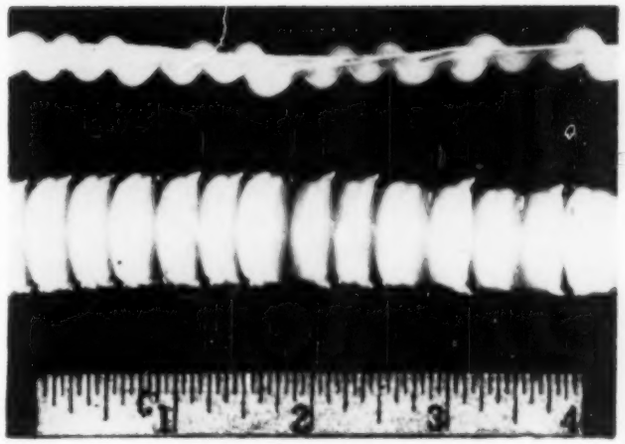

Fig. 2—Extrudate with buckled mid-section.

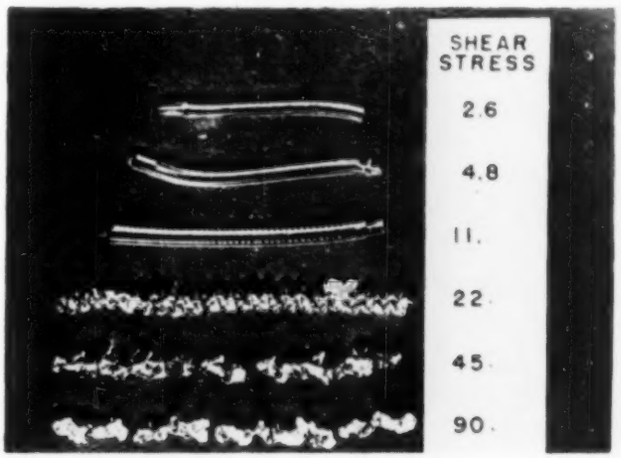

Fig. 3—"Lucite" 140 specimens. Extrusion conditions: 0.047 in. diam., 0.008 in. long, flat inlet capillary; 170°C (338°F); shear stresses, those shown by 10^6 dynes/cm^2. Scale: shear stress legend was photographed with specimens; the characters were 1/8 in. in height.

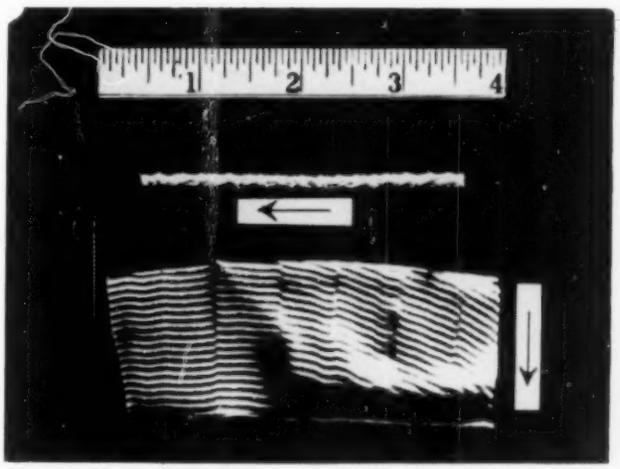

Fig. 4—Melt fracture in wire coating and extruded film (extrusion direction indicated by arrows).

This paper was presented at the 12th SPE Conference.

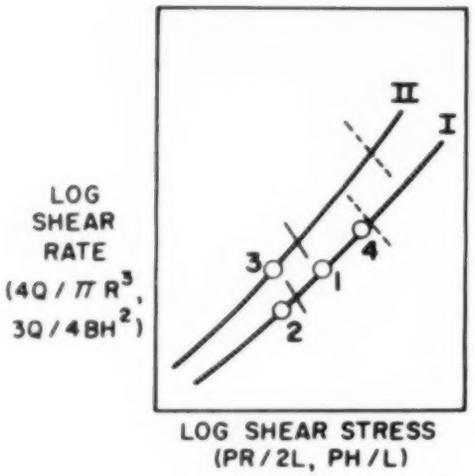

Fig. 5—Schematic flow and fracture data. (Short slanted lines, solid and dotted, indicate incidence of fracture depending on inlet geometry.)

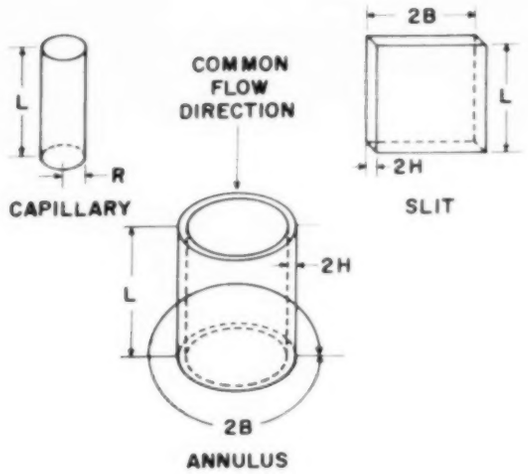

Fig. 6—Die geometry designation for slits and capillary.

dicular to the direction of flow.

The effects of melt fracture described above are characteristic of all thermoplastics. However, the magnitude of the effects, the degree of surface roughness decreases with viscosity of the resin. Thus, at 270°C, the effects are barely visible in "Lucite" 140. Likewise "Zytel" 101 and 61 nylon resins have such low viscosities at their extrusion temperatures that the effects of melt fracture are barely visible. With many commercial resins at common extrusion temperatures, substantial amounts of irregularity result from melt fracture at pressures above the critical pressure.[4]

In view of the trend in plastics technology toward higher rates of fabrication, it appeared important to understand the causes of this type of surface irregularity. These are discussed in detail elsewhere.[2] It was also important to learn the methods of avoiding incidence of this type of irregularity.

Elimination Of Melt Fracture

Since melt fracture occurs at and above a critical stress, it may be avoided by suitable manipulation of the extrusion variables to keep the stress below the critical level. This is discussed below first, in terms of extruder operation and, then, in terms of the flow variables, shear stress and shear rate.

A. In Terms of Extrusion Variables

Any combination of the following methods may be used to reduce the shear stress to eliminate melt fracture.

1. Lower the viscosity by raising the temperature or using a "softer" resin.

2. Use a streamlined or gradually tapered inlet. This tends to raise the pressure and throughput.

3. Open up the die. (A higher draw ratio may then be required to maintain desired caliper.)

4. Lower the throughput by reducing the pressure.

Of the above expedients by which melt fracture may be avoided, use of streamlined inlets may be the most attractive. No other change in the operation may be required. On the other hand streamlined inlets appear to be conventional. In cases where the die inlets appear to be effectively streamlined, little or no advantage may result from efforts toward better streamlining.

B. In Terms of Flow Properties

The conditions under which melt fracture occurs and the methods of eliminating melt fractures may be shown simply in a shear stress vs. shear plot, see Fig. 5. The important feature of this type of plot is that the **flow properties** of the plastic are shown rather than only the characteristics of a single die. Using shear rate and shear stress coordinates, flow in a 1" pipe may be compared to flow in a 0.015 in. gap slit die (with the restriction that the relative die lengths, as described below, are comparable). The horizontal axis is maximum shear stress, which is dependent on pressure and die dimensions. Shear stress is the driving force, the force per unit area, pushing the plastic through the die. For a capillary, shear stress is the product of the pressure and radius of the hole divided by twice the land length, PR/2L; for a slit, the product of the pressure and the half-gap divided by the land length, PH/L. (See Fig. 6.) An annulus may be considered a special case of a slit.

The vertical axis in Fig. 5 is shear rate which is dependent on the flow rate, Q (in volume per unit time i.e. in.³ sec or cc/sec), and die opening (not length). Shear rate describes the rate at which separate flow elements of the melt slide by each other rather than merely the flow rate. Shear stress and shear rate may be considered reduced coordinates which are largely independent of die dimensions.[3]

[4] *The critical pressure will vary with die geometry.*

[3] *The relative length of the die, L/D or L/4H, must also be considered. As shown schematically in Fig. 10 shear rate may depend relative length as well as shear stress (and temperature).*

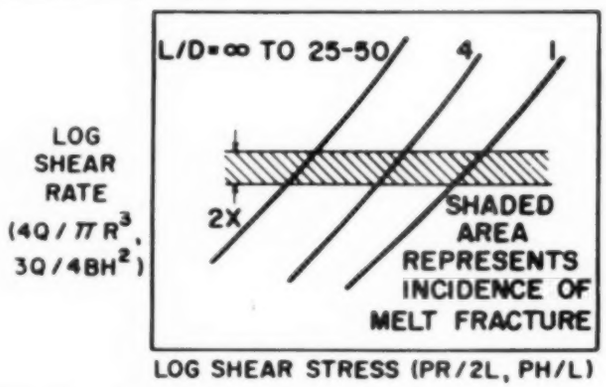

Fig F—Effect (schematic) of relative die length on melt fracture. (Parameter—L/D or L/4H ratio.)

The lower shear stress, sheer rate curve, I in Fig. 5, represents the flow of one plastic in any long die, or in a given L/D or L/4H ratio short die, at one temperature. The upper curve, II, represents flow of the same resin at a higher temperature, or the flow of a softer grade resin at the same temperature. The short slanted lines (either solid or dotted) indicate the conditions at which melt fracture occurs. At and above the stresses and rates indicated by these marks, melt fracture occurs.

The four methods listed above to eliminate melt fracture all amount to lowering the stress at the site of fracture. One of the methods is to lower throughput by lowering pressure. (Here and in the following until specifically mentioned, we are concerned with incidence of fracture at the solid slanted lines in Fig. 5.) Lowering the pressure corresponds to going from point 1 to point 2 in Fig. 5 by lowering P and leaving the die dimensions fixed. This will also lower the shear rate and the output of the machine, Q. The exact amount these will decrease is determined by the slope of the curve for the particular plastic. However in round numbers, flow in this region is proportionate to the 2 to 2.5 power of the pressure; for half the pressure flow rate will be only 1/4 to 1/6 that at initial, full pressure. Lowering the pressure and throughput may be the least desirable way of eliminating melt fracture.

Melt fracture may be eliminated by raising the temperature. This lessens the resistance to flow and results in higher shear rates at a given stress as indicated by curve II in Fig. 5. As a result it is possible to eliminate melt fracture and maintain the same throughput or shear rate by raising the temperature and lowering the pressure or shear stress. This amounts to moving from point 1 to point 3 in Fig. 5.

Use of a softer grade or less viscous resin has the same effects as raising the temperature.

In the event the above expedients are unsatisfactory, then the die geometry must be modified. The simplest modification of the die is to streamline the inlet. This may reduce the stress in the inlet where this type of melt fracture occurs and result in a higher shear stress and shear rate without incidence of melt fracture. In Fig. 5 this amounts to moving the location of incidence of melt fracture from solid slanted lines up the curve to, for instance, the locations shown by the short dotted lines. Thus, with a streamlined inlet point 1 lies below the fracture stress. As a result of streamlining, shear rate increases like that represented by point 4 relative to point 1 in Fig. 5 may sometimes be obtained without occurrence of melt fracture.[6]

On the other hand, melt fracture may occur in extrudates from dies whose inlets are streamlined. In this case, little or no gain in shear rate without incidence of melt fracture may result from further efforts at streamlining. In effect the lower, solid slanted lines in Fig. 5 represent the maximum stress obtainable without fracture in such a die. If this is the case, and if it is still desired to keep the same throughput, Q, as indicated for point 1 or even increase it, then it is necessary to alter the **die opening** as described below.

The shear rate at incidence of melt fracture depends on the plastic, on temperature and on the geometry of the inlet. The flow rate or throughput rate at fracture depends, in addition, on the size of the die opening. The flow rate at incidence at melt fracture varies inversely as the third power of the radius for capillaries and inversely as the second power of the gap for slits. Obviously, increasing the die opening will result in increased flow rate but the dimensions of the extrudate will change also. In some cases melt draw may be used to produce suitable final dimensions.

Changing the land length has little effect on melt fracture. Fig. 7 is a schematic representation of the dependence of shear stress—shear rate curves at a constant temperature on relative die length, L/D for a capillary and L/4H for a slit. The shaded area indicates

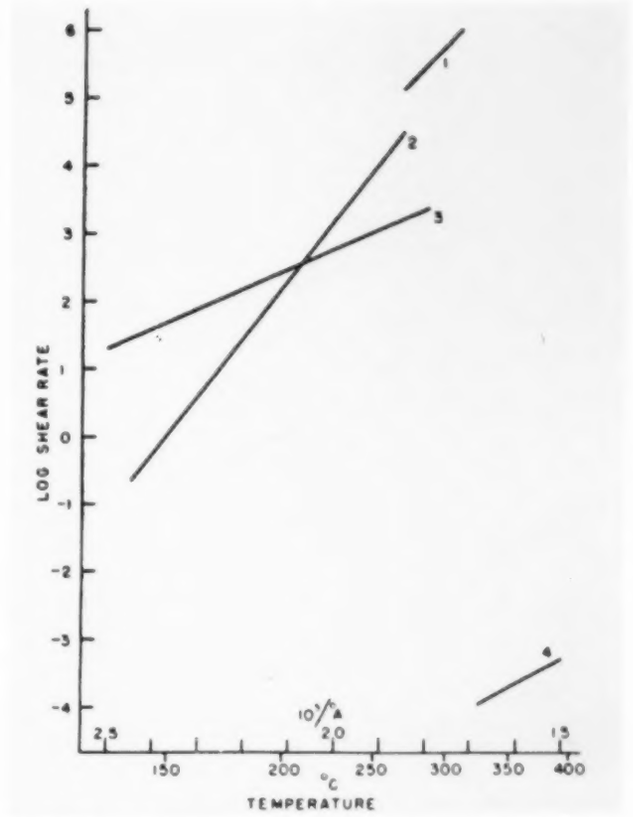

Fig. 8—Shear rate at melt fracture vs temperature for (1) "Zytel" 101, (2) "Lucite" 140, (3) "Alathon" 14, (4) "Teflon" TF-1.

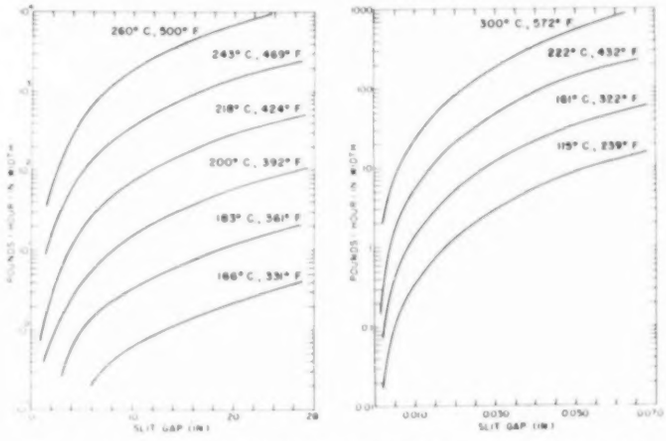

Fig. 9—Shear rate of "Alathon" 14 at incidence of fracture in flat inlet, slit dies.
Fig. 10—Shear rate of "Lucite" 140 at incidence of melt fracture in flat inlet, slit dies.

[6] *W. H. Darnell of this laboratory found that the shear rate of polyethylene could be raised by at least a factor of ten by using 20° included angle, conical tapered inlet to a capillary in place of a 180°, flat inlet.*

the shear rate range over which melt fracture occurs. The variation in shear rate at incidence of melt fracture for "Alathon" 14 polyethylene resin and "Lucite" 140 acrylic resin was only two-fold or less for the range 50 to 0.1 L/D. The two-fold variation appeared to be random and was considered to be the limit of accuracy of determination of the shear rate at incidence of fracture. As a result, shear rate at fracture is considered independent of relative die length. Increasing the die length does tend to reduce the degree of the irregularity produced by melt fracture. However, the amount improvement associated with use of long lands is small and this is not considered a practical method of eliminating the irregularity.

Melt Fracture Data for Several Resins

The variation with temperature of shear rate at incidence of melt fracture is shown in Fig. 8 for several resins. Approximate values of shear rate the incidence of melt fracture in flat inlet dies are given for "Alathon" polyethylene resin, "Lucite" 140 acrylic resin, "Zytel" 101 nylon resin, and "Teflon" TF-1 tetrafluoroethylene resin. At shear rates above the respective curves, melt fracture occurs. For streamlined inlet dies the curves would lie higher by an amount which would depend on the effectiveness of the particular contour.

The data in Fig. 9 may be converted to "working charts" which are less general but perhaps more convenient. Pounds per hour throughput per inch of slit width is plotted against the slit gap for "Alathon" 14 and "Lucite" 140, respectively. Separate curves are drawn for each of several temperatures. Again, at flow rates above the respective curves melt fracture occurs in flat inlet dies; for streamlined inlet dies, each curve would lie higher by an amount depending on the effectiveness of the contour in reducing the stress in the inlet.

Melt Fracture In Melt Drawing Operations

While melt fracture may occur in extrusion die inlets, it may also occur in other types of operations wherein the melt is sheared. An example is melt drawing. The same considerations which applied in the case of flow in a die also apply here. Whenever the drawing conditions are such that the amount of energy stored elastically in the melt exceeds the cohesive energy of the melt fracture will occur. This may well be the cause of tearing in the melt drawing of thin film, and breaks in the drawing down of an extruded coating on wire.

Melt fracture can occur by melt draw in extrusion through irregular dies when no external force is applied to produce melt draw. In dies of varying cross section as typified by Fig. 2, melt fracture can occur in the thin section of the extrudate. If the extrudate flows at a rate approximating the high linear flow rate through the large cross section of the die, that part of the stream which flows slowly from the thin section of the die will be melt drawn. In such a case, melt fracture may result in saw teeth or tears perpendicular to the flow direction along either edge of the extrudate.

Elimination of melt fracture in melt drawing operation would be accomplished, as in the case of flow in dies, by reducing the stress. Stress may be reduced by any combination of the following: higher temperature, softer grade resin, increased length over which draw occurs, lower throughput and draw rates, reduced amount of draw.

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WRITE FOR LITERATURE

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Action— By Your National Organization

"The objects of the Society shall be to promote in all lawful ways the Arts, Sciences, and Engineering Practices and Standards connected with the utilization of plastics."

New National Directors

In accordance with By-law 43 of the Society's Constitution and By-laws we take pleasure in announcing the election of the men listed below as new National Directors of the Society whose terms of office begin this year.

Section	National Director
Central Ohio	William L. Croll
Detroit	Roy A. Smith
Ontario	John L. Burnie
Philadelphia	Norman A. Skow
St. Louis	Walter P. Bussart
Southeastern Ohio	Paul H. Brill
Western New England	George W. Martin
Worchester Leominster	Albert R. McIntyre

SPE Representatives

A Cooperative Technical Program Committee has been organized during the past year which is made up of SPE members who represent the Society in 22 other technical and engineering societies allied to plastics engineering.

J. Harry Du Bois is Chairman of the entire Committee which is part of the Professional Activity Committee (PAC) of the Society. The Subcommittee chairmen are:

Chairman	Society
L. F. Rahm	American Society of Mechanical Engineers
Dr. Norman Skow	International Standards Organization
J. Delmonte	Society of Motion Picture & TV Engineers
R. V. Beshgetoor	Institute of Radio Engineers
W. B. Hoey	Society of Automotive Engineers
J. L. Bonanno	American Institute of Electrical Engineers
R. B. Bishop	Manufacturing Chemists Association
F. J. Donohue	American Chemical Society
R. G. Drewes	Instrument Society of America
R. L. Shanta	American Institute of Chemical Engineers
W. Lewi	American Standards Association
J. L. Haugsrud	American Society for Quality Control
H. H. Dash	American Association for the Advancement of Sciences
W. B. England	Armed Forces Communications & Electronics Association
J. M. Church	Engineers Joint Council
F. W. John	American Society of Safety Engineers
R. S. Perkins	National Society of Corrosion Engineers
Dr. L. Gilman	American Ordnance Association
W. Larson	ASTM-SPE-SPI-Pipe Committee
A. W. Logozzo	American Electroplaters Society
J. Fuller	Institute of Aeronautical Sciences
G. Thayer	American Society of Testing Materials

During 1956 you will be hearing more of the activities of this group.

P. L. Underwood

Executive-Secretary

THE *Injection* MOLDERSCOPE

By A. R. Morse

President, Injection Molder's Supply Co.

"It is the freedom to disagree, to quarrel with authority, in intellectual matters to think otherwise, that has made this nation what it is today." Dr. James B. Conant

Injection Molding of Polyethylene

Part 2. Heating Chamber Problems

Last month I introduced the subject of injection molding polyethylene and covered some of the problems engendered by the nature of the material itself — problems about which the injection molder can do but little except to switch hopefully from one batch of powder or one material supplier to another. This month, I am discussing a phase of the problem that is within the scope of the molder to do something about, and that is the heating cylinder.

The most common difficulty encountered with polyethylene is the appearance of black flakes or "dirt" or "burns" in the molded article. We have found that this comes from an area confined to about 3-4 inches in the back of the cylinder just ahead of the plunger. What causes it is still a matter of intense speculation. Can it be that gas or air trapped at this point, and that we have a problem of oxidation? It could very well be, because the polyethylene has a marked tendency to stick to the cylinder wall, especially in the temperature range found in the back of the typical heater. Further forward where the cylinder wall gets hotter, the material flows better, and we do not find this black oxide layer. In other materials it is not so pronounced as they remain somewhat porous and the gas can get out thru the impacted material or along the walls, but not so (apparently) with polyethylene.

It is commonly observed that these black flakes follow sharply on start-ups, and often taper off altogether as production continues. This we can assume to be caused by shrinkage of the cylinder wall on cooling at shut-down. At the startup, the cylinder wall expands by a measured amount and the black coating flakes off, having been cracked by the contraction and expansion of the underlying steel.

There are several comments to be made in this connection. If a cylinder is used consistently on polyethylene, most present design original equipment heaters soon take on this black coating in the given area, and flaking soon appears. Often it seems that the harder the cylinder is pushed the less likely the "black" is to give trouble. If the heater is shut down with polystyrene in it, or if it is used on a variety of materials, it seems less likely to give off a high percentage of black flakes. As yet, there is no real correlation between the scrap rate from black flecks and cylinder heats. I have seen cases where the scrap rate was cut down and where it was also increased by raising the cylinder heat.

The wide molding range of polyethylene, and the wide variety of heater designs now in use, coupled with the tremendous differences in heat loss into the various types of cylinder mountings, plus the variation introduced by changes in thermocouple location, all make this problem of pinning down the exact cause of black flecks a difficult one. We ourselves are in an enviable position, because we apply a uniform design heating chamber for **any** type of press. Therefore we can at least make some headway in assessing the effect of heat loss to the cylinder mounting thermocouple contact points, and other variables that can well be minimized between different types of machines, by using one design of heating cylinder. Our problem is complicated however, by differences in plunger size and stroke, and by differences in plunger speeds and pressures found on all the various machines, so that any conclusions we make must always come back to the specific performance and design factors inherent in the press itself. But by re-designing the back-end of the cylinder we have definitely been able to reduce, if not to eliminate, the formation of the oxide layer that is causing black specking on almost every make of press. The design to accomplish this forces cleaning or scouring of the cylinder wall. We do not judge it to be entirely suitable for materials not in the general elastomeric classification, as on other types of powders it might result in a considerable pressure loss that we do not get with polyethylene. The design does increase pressure requirements and appears to reduce heater capacity so further modifications are being studied to minimize these objections.

Other causes of black specks must be mentioned, as they are common enough. Dirt under the nozzle seat is one source; and a mismatched nozzle sprue bushing fit using a heated nozzle is another. A defective heater joint can cause flecking of polyethylene, whereas the same trouble in styrene would appear as a streak. In this material however, the flecks are let go and get pretty well mixed up by the time the stuff reaches the mold so that we have an effect of random distribution that would tend to lead us away from the idea of a "leaky" joint. Of course, bolts and other foreign objects will also hold up the plastic, and flecks will let go. We are used to diagnosing heater trouble by a rule of thumb that states if the streak (in styrene) appears in one place in the sprue, in the runner and the molded part, then we are sure of a parted joint, a broken spreader or tramp metal, whereas, if the "dirt" appears at random without a pattern it is caused by burning, charing, or overheating from numerous causes, usually cycle interruptions where regular purging cannot be carried out. In polyethylene, however, the flecks do not follow the same general rule of cause; and it is far more difficult to pin down their actual source. Sometimes, indeed, they are caused by de-composition of the plastic itself, and have repeatedly appeared in given instances when all other known causes were investigated and removed, and inspection revealed that the interior surface of the heater was perfectly clean and carbon-free. Here, **only a change in batch and/or make of material was the solution to the problem,** although I feel equally sure that if a heating chamber of the proper design were installed the scrap rate could be held within an acceptable minimum on any make of powder. The design of a heater for polyethylene must include a re-appraisal of the amount of the wattage used, the location where it is applied, together with a redistribution of its density and the rate of its appearance on the wall surface INSIDE the heater so as to minimize sticking of the plastic at a certain point which in turn causes gas-trapping, burning, or whatever is the source of the formation of the troublesome "flecks" that push polyethylene scrap rates well beyond those experienced with styrene.

While many molders will balk at the installation of a single-purpose heating chamber for polyethylene, there is already ample evidence that there is one sure way to hold the scrap rate down. There are other factors, however, involved, ranging from mold finish to nozzle design that I will comment on next month.

AROUND THE WORLD

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GREAT BRITAIN

PLASTICS

Oct., 1955

Abstracter: Alfred T. Rexer

COMPOSITE FLEXIBLE HOSES USE PLASTICS — Page 398 to 401 incl.

Description of a number of special purpose hoses using such plastics as terylene polyvinyl chloride nitrile rubbers, polytetrafluoroethylene. The materials to be conveyed through the hose decide the choice of plastic, they include: air, gas, oils, steam, acids, fuels and gasoline. Hoses can be made to withstand high and low internal and external pressures, repeated flexing and high and low temperatures.

SURFACE TREATMENT OF MOLDINGS — by Maurice Fuzzard—Pages 413 to 415, 437

Decorative treatments of plastics moldings are particularly important for polystyrene and polyacrylics. The products to be decorated with paints or lacquers must be essentially strain free; tests for stress are therefore discussed and also annealing as a means to eliminate stresses. Solvent attack must also be carefully considered, the solvent resistance of the molded plastic must be known, generally only air drying lacquers can be used, but still there is a wide choice of lacquer basis, for instance, phenolics, alkyds, vinyls, styrenes, cellulose derivitives and even isocyanates. Many methods of application are brushing, spraying and roller coating. A spray gun is illustrated and its operation is briefly discussed. Some common faults are mentioned and remedies suggested (pin holes, blushing, orange peeling).

SOME USES OF POLYURETHANES IN ELECTRONICS AND SURFACE COATINGS — by J. Brennan—Pages 417 to 420 incl.

Mainly a discussion of the electronic application of isocyanates in impregnation and incapsulation of such products as transformers and coils. The isocyanates are also used for potting and are able to withstand extreme climatic conditions. Low viscosity at room temperature is required for easy bubble free pouring. A long pot life is wanted, but is difficult to combine with fast curing.

A typical potting formulation contains 20 to 40% of 2, 4-meta-toluylene di-isocyanates, 0 to 10% styrene and 80 to 50% of castor oil. After pouring, the potted composition is left at room temperature till gelation has occurred (6 to 60 hours) and is then cured at 60 to 100°C and 12 to 36 hours, of course, the properties of the cured compound vary with its composition. The influence of variations in percentage styrene and percentage di-iscyanates is on the dielectric properties illustrated in a number of graphs. Polyurethane coated magnet wire is a ready available product in Europe, it is solderable at 350°C, electrical properties and chemical resistance are excellent.

THE MANUFACTURE OF EPOXIDE RESINS — Pages 424 to 425 incl.

Short description of the new Shell plant in Stanlow, where the Epikote, (Epon), line of Shell epoxides are made with a capacity 2000 tons a year. The Epikotes are based on Diphenylol propane and Epichlorohydrin condensed in the presence of a 46% caustic soda solution. At present the Epichlorohydrin is imported from the United States.

DERMATITIS — AN INDUSTRIAL PROBLEM — by E. E. Lieber—Pages 428 to 429 incl.

The author is a medical officer who has a long experience with cases of hypersensitivity and allergy to many reagents. The lists of reagent includes phenol - formaldehyde resin urea - formaldehyde resin, polyester resin, styrene, rubber latex, phthalic anhydride, glycol, formaldehyde, epoxides, di-isocyanates, and glass fibers. A description is given of the symptoms, case history psychological and sometimes psychiatric implications.

November, 1955

VACUUM FORMING — Pages 358 to 372 incl.

In four sections entitled: The Process; The Materials; The Products and The Equipment, a fairly comprehensive discussion of vacuum forming has been given. Straight forming is described as opposed to drape forming. The first method is best suited to shallow articles whether male or female molds are used. Male molds have the advantage that the difficulty of thinning is largely avoided, female molds are simpler and cheaper. A limitation of vacuum forming is that, of course, only a pressure of rather less than one atmosphere is available for shaping. An advantage, on the other hand, is because of the low pressures, cheap molds are feasible. Many different materials can be vacuum formed, they include: vinyls, acrylics, polystyrenes and cellulose derivitives. The softening range usually lies between 70 and 90°C, although, the actual molding range may be much higher. The heat softening is sometimes done with radiant heaters mounted on the forming machine proper. The products include: display items, signs, packaging, trays and refrigerator parts. A wide range of semi-automatic equipment is available for the process; an interesting development is the extruder fed equipment developed by R. H. Windsor, Ltd. This machine can also perform as a laminating unit. It can handle sheets of 36" x 60" and 60" x 96".

ELASTOMERIC INJECTION MOLDING COMPOUNDS FROM VINYL RESINS — by T. C. Young — Pages 378 to 382 incl.

If a number of basic principles is observed, Vinyl Resins can be successfully injection molded. The material must be adequately and homogeneously softened without over heating. Overheating may cause degration, (hydrochloric acid), but this can be inhibited by the use of so called stabilizers. As high temperatures greatly increase the tendency to decompose, the lowest possible molding temperatures should be maintained. The choice of a good lubricant and of a co-polymer can lower the molding temperature. The cylinder and nozzle should be streamlined and preferably plated. Best results are obtained when the molds are rapidly filled, short sprues and runners are advisable. Pin point gating has proved to be particularly successful.

STYRENE AND THE SURFACE-COATING INDUSTRY —by W. E. Allsebrook — Pages 383 to 385 incl.

Styrene is cheaper than most other

raw materials and a large production capacity is available, therefore, application as a lacquer base is attractive. The author discusses numerous possibilities for styrene application most of them in combination with other raw materials. The discussion includes; styrenated oils (should contain a proportioned conjungated bonds for homogeneous co-polymerization), styrenated alkyds, (improved water and alkali resistance, again conjugated double bonds must be present), emulsion resins, (styrene butadiene co-polymers are already a 40,000,000 gallons a year proposition in the United States, representing 20 to 25% of the indoor paint market), styrenated epoxide resin esters, (esters of fatty acids containing conjugated double bonds). A new development is the substitution of vinyl toluene, (a mixture of m- and p-methyl styrene), for styrene because of the lower price of the vinyl toluene.

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BELGIUM

DIGEST DE MATIERES PLASTIQUES

No. 78, Sept.-Oct., 1955

Abstracter: Alfred P. Daignault

POLYMERIC PLASTICIZER STABILIZERS — by Raymond J. Rauet — pps. 9-15

This paper presented to the November 1954 meeting of the Swedish Federation of Plastic Materials is reported in English under the following headings: (1) Introduction; (2) Permanence and Related Characteristics; (3) Physical and Physiological Properties; (4) Stabilizing Properties; (5) Economic Aspect; and (6) Conclusion.

ANNIVERSARY OF THE DEATH OF J. E. BRANDENBERGER, INVENTOR OF CELLOPHANE—pps. 16-17

(from the Revue des Products Chimiques Paris)

A short chronological history of the developments leading to the successful production of cellophane as we know it today.

FIBER SPONGE SHOCK ABSORBER MOLDED INTO CORRUGATED PACKING — pps. 17-18 (from "Food Processing")

Description of "Pillo-Pak," "Pillo-Flex," and "Pillo-Board" packaging materials of the Packaging Materials Corporation of New York.

ILLUSTRATED APPLICATIONS OF PLASTIC MATERIALS—pps. 20-21

(a) Vinylite based coating for steel drums; (b) Fiberglass reinforced plastic billboards.

LISTING OF GERMAN PLANTS HOLDING OPEN HOUSE DURING INTERNATIONAL PLASTICS FAIR OF 1955 — p 22

NEWS OF THE WORLD — p. 23

(a) Belgium — French synthetic fibers at Brussels International Textile Exposition — Nylon, Rhovyl, Tergol (a polyester fiber) and Crylor (an acrylic fiber).

(b) U.S.A. — Announcement by Du Pont of construction of pilot plant for production of low pressure polyethylene. Short description of Minnesota Mining and Manufacturing Co.'s new tape, Scotch 549; Garage doors of fiber glass reinforced polyester resins; GE silicone base lubricant for high temperature applications—"Polymekon Wax"; "Dow Corning 36 Emulsion"; Silicone base wax for protection of combustion chambers; Use of Dacron in paint rollers; Announcement of the Union Carbide Nuclear Co. and other Carbide & Carbon Corporations activities in the atomic energy field; "Palladium Liquid Neoprene" protective coating; Truck & Trailer bodies of fiber glass reinforced polyesters; Cohrlastic HT Molding 400 & Extrusion 600 silicone rubber (Connecticut Hard Rubber Co.); "Ludox" — to reduce soiling of rugs, upholstery, draperies, etc.; Plastic film in roofing and insulation; Listing of bulletins from "Plastics Technology" (May & June).

Holland — Plastic materials in the Graphic Arts; Isocyanate based rubber (from July & August 1955 issues of "Plastica").

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SWEDEN

PLASTIC ASSOCIATION TECHNICAL BULLETIN

Abstracter: Walter Werber

Volume 10, No. 10, March, 1955

BALANCED GATING FOR INJECTION MOLDING—D. A. Jones

This hotly controversial subject is discussed in detail with the help of formulas and charts. A very useful discussion and one which will give food for thought to many injection specialists.

Volume 10, No. 12, March, 1955

STUDIES ON PLASTIC PIPES FOR PORTABLE WATER SUPPLIES — Walter D. Tiedeman

Comprehensive analysis of the chemical aspects of water transportation and the part plastic plays and will play in the future.

Volume 10, No. 18, May, 1955

FACTORS AFFECTING THE HIGH SPEED TAPPING OF PLASTICS—W. M. Halliday

The author uses numerous examples to describe his point of tapping of different plastics.

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Dear Friends:

We will now stand and give three cheers for the Cleveland-Akron Section for the fine job they did on the 12th Annual Conference. Of course, there were a few rough spots that were pretty hard to anticipate because of the "greater than anticipated" attendance. After all, 2400 people in the same spot is a lot of people and no one has yet found a way to miniaturize his fellow man.

The highlight of the Conference, so far as I was concerned, was Dr. Guyer's speech at the banquet. I had personally made guarantees to several persons concerning the quality and I am still waiting for them to claim their refund. Another outstanding fact was the multiplicity of methods represented in the papers read at the Conference. A few instances of flat contradictions were noted. These contradictions point out that perhaps the method of doing a thing is not the most important after all and that the important thing is the result obtained.

Mr. Jerry Formo's suggestion that we rephrase the perennial question of "What do I get for my dues?" to "How much can I contribute?" was a good suggestion. I am sure we all wish Jerry a most successful year. After all, it is only a little over 11 months till the next conference in St. Louis so we don't have much time to get ready.

Yours for better living with plastics,

Wayne I. Pribble

WAYNE I. PRIBBLE, President

SECTION NEWS

Edited by
Stanley Bindman
Jamison Plastic Corp.
1255 Newbridge Road
North Bellmore, L. I., N. Y.

Toledo

Glass City Section Has Annual Ladies Night At Hillcrest Hotel

D. E. Cordier

On Tuesday night, November 22nd, the Toledo Section of Society of Plastics Engineers held their annual Ladies' Night at the Hillcrest Hotel. Twenty-eight couples enjoyed the dinner and program which opened with drawings for door prizes and drawing for a mink scarf. Mrs. Andy Kassay was made extremely happy when she became the winner of the scarf.

The speaker of the evening was Mr. William Connolly, Assistant Director of Public Relations of the Bakelite Company. He first amazed the ladies with a beautifully illustrated talk by means of colored slides and then astounded them with a series of quickly executed magic tricks. Participation of the ladies in the magic acts added special interest to the clever tricks. All present enjoyed the pleasant surprises.

Mr. Connolly's talk was titled "Plastics Used in Home Decoration" and it described types of floor tile, wall tile, wall covering, lighted ceilings, other illuminating applications, and special decorative effects made possible by the use of plastics.

Bob Lowry and Elmer Faber handled the arrangements and details of the meeting.

December

The December meeting of the Toledo Section was held at the Stork's Nest Restaurant on December 14th, with approximately 20 members and guests present for the dinner.

Following the dinner, Program Chairman Bob Dunham introduced the speaker of the evening, Mr. Hamilton E. MacArthur of Conforming Matrix Corporation, Toledo. Mr. MacArthur, who is a member of our own Toledo Section, spoke on the subject "Color Decoration of Plastics by Usse of Electro - formed Spray Painting Masks."

In an interesting illustrated address, Mr. MacArthur first described the production of precision electroformed masks from copper or nickel. The various types of masks were described and their use shown: the lip mask for painting designs on areas depressed in the part, the plug mask for protecting the depressed area and painting the raised portion, and the block cut-out mask for efficient painting of areas to be wiped-in, such as fine lines or lettering. The practical application of these masks to mass production of contrasting color and multicolored plastics items was illustrated by an excellent film on this subject. This film not only demonstrated the masks in operation, but also showed the special tools and fixtures and automatic spray painting machines which represent the adaptability of the process to mass-produced precision decoration problems. Typical applications include automobile horn buttons, escutcheons, name plates.

The meeting closed with a lively question and answer period on the spray painting process. In this discussion it was brought out that multicavity molds often require separate masks, even if the cavities were made from the same hob, so essential is the need for absolute fit in some painting problems.

During the business portion of the meeting newly elected officers and directors were announced as follows: President, Frank B. Rosenberger; Vice President, R. E. Dunham; Secretary, Don Bowlin; Treasurer, Elmer Faber; 3-year Directors, R. E. Dunham, W. E. Fillmore, Erik Kohler; Director to fill unexpired term, James L. Bernard.

The following new members were announced by President Don Bowlin: Amos H. Aigler and William S. Gould, both of Aigler Tool & Die Company; Otto J. Basilius and Vernon J. Basilius, both of Basilius Grinding & Tool Company, and Gerald D. Schmidt, Advanced Products Company. These additions bring the membership of the Toledo Section to 75.

Connecticut

'Stump Experts' Program Held

David Mersey

At the December meeting, announcement was made of the election of the following new directors: Edward Ferarri, General Electric Co.; Rene Magnenet, Waterbury Companies; William Coughlin, Naugatuck Chemical Co.

The new officers elected were: David Mersey, president; Edward Ferarri, vice-president; Carl Svenson, treasurer; William Coughling, secretary.

The major part of the meeting was devoted to the annual "stump the experts program" with prizes of fifteen, ten and five dollars going out as prizes for the three best questions. The panel of judges were: Elias Greninger, Bryant Electric Co.; Rene Magnenet, Waterbury Companies; Richard Scalese, Atlantic Plastic Co.

Some of the major questions that were asked are as follows:

First Prize Question: With the advent of so many new thermoplastics, especially the styrenes and polyethylenes, with so many different commercial names, would it not be advisable to assign a number to each formulation (regardless of the material manufacturer) similarly as is done in the metals industry.

Second Prize Question: Does annealing polyethylene parts avoid a peeling effect as is sometimes found near the gate. The answer to this question is that annealing might help stabilize the compound, but not necessarily remove the cause of the lamination.

Third Prize Question: How to remove flash from molded nylon parts. Many answers were suggested, including the use of wet and dry pumices, however, this abrasion technique might change the surface appearance and dimensions of the molded parts.

Several asked . . . how to retain or impart good flexibility to parts molded of nylon 101. Answer . . . perhaps the most important factor is control of cylinder temperature, i.e., the cylinder temperature controls the life of the nylon.

A tool maker wanted to know, "what are the most outstanding faults of tools received from the tool maker?" Answer . . . most faults are with tools made not by tool makers, but with those claiming they are tool makers.

Great interest was shown in low-cost, short-run molds; such as epoxy molds and their life expectancy. Answers indicated that these were of lower cost than metals molds.

Milwaukee

New Meeting Places Selected; Plans For Activities Announced

Marvin C. Stowe

The Milwaukee Section of the Society of Plastic Engineers held its December meeting December 13, 1955 at the Bavarian Club, Milwaukee, Wisconsin. This is a new meeting place for the Section and it's probably the nicest place at which a meeting of our type could be held. We have our efficient house committee, headed by Ken Charter, to thank for this improvement.

After a fine roast beef dinner a business meeting was held. Some of next years plans were revealed by the various committee heads. One of the things on next years schedule is a planned tour through the Molding Department of Cutler-Hammer Inc., Milwaukee, Wisconsin. Also, during the business meeting new officers were installed as follows: President, Charles E. Egan; Vice-President, Marvin C. Stowe; Secretary, Ken Charter; Treasurer, John Canning; National Director, Eugene Slingluff. Also elected as Directors for a three year term were William P. Gobeille, A. P. Anderson and John Verburg.

The occupations and the Companies that they represent are as follows: Charles E. Egan, Manager of the Milwaukee Branch of Owens-Canning Fiberglass; Marvin C. Stowe, Assistant Manager of Stowe Plastic Products, Milwaukee, Wisconsin; Ken Charter, Project Leader in the Ceramic, Organic Research Lab., A. O. Smith Corp., Milwaukee, Wisconsin; John Canning, Evaluation Chemist in the Plastics Lab., Molded Products Department, Cutler Hammer Inc., Milwaukee, Wisconsin; Eugene Slingluff, Vice-President and General Manager of Sunlite Plastics Inc., Milwaukee, Wisconsin; William P. Gobeille, Plant Manager of American Motors Corp., Milwaukee, Wisconsin; A. P. Anderson, Project Leader in the Fiberglass Plastics Lab., A. O. Smith Corp., Milwaukee, Wisconsin; John Verburg, Quality Control Head, Plastics Division, Continental Can Co., Inc., Milwaukee, Wisconsin.

In stepping down from the President's job, Mr. John Verburg thanked each and every one for the cooperation he has received during the past year. I think we all would like to thank John Verburg for a job well done. The Milwaukee Section has certainly gone forward in this past year.

As guest speaker for the evening we were honored with Mr. Joseph L. Cross of the A. O. Smith Corp., Milwaukee, Wisconsin. Mr. Cross spoke on "Human Relations As A Means of Increasing Manufacturing Efficiency." The important part of the lecture was human relations between management and labor. Both management and labor can work together for a mutual benefit. Several of the large Companies including A. O. Smith Corp. have set up human relationship training programs. Large amounts of money have been spent for these programs, however, it has paid off production wise. You have good human relations when each man understands and respects his fellow man, regardles of position or rank. Here are a few examples of how not to get results through people that may be working for you. 1. Keep each worker guessing, avoid praise, he'll ask for a raise. 2. Give him hell once a day, be sure you have an audience. 3. Let **him** find out about changes that will effect him, do all the thinking yourself, order him to change or else. 4. Let each worker know how unimportant he is, you got along without him once—you can do it again. These are a part of the old belief "You can lead a man to the job but you gotta make him work." As more and more experiments have been completed involving human relations with production, they have proven that people enjoy working when they have an **important job** to do and when they are a part of the team.

What does an employee look for in a job? A good share of management and proprietors might say money. To disprove this old-fashioned idea a survey was conducted in a very large manufacturing concern and these ten most desired factors were brought out. 1. Security; 2. Type of work; 3. Company reputation; 4. Kind of supervision; 5. Co-workers; 6. Advancement possibilities; 7. Working conditions; 8. Benefits; 9. Pay; 10. Working hours. This brings out that it is impossible to buy a mans rights, liberty, honor, self-respect or pride.

In summarizing Mr. Cross' speech, we will say, where there is good human relations there is generally an incentive to create and usually the increased production and better quality.

Detroit

Ladies Attend Party

Mac Nichols

The Annual Christmas Party for the Detroit Section was held on December 16th in the Grand Ball Room of the Sheraton-Cadillac Hotel and the red carpet was rolled out for 310 members and guests.

This party was unique, in that it was the first social event given by the local section to which the "Ladies Auxiliary" were invited, and the Ball Room was filled with charming ladies in stunning gowns that must have caused some of the boys in our Plastics Fraternity to wince when the bill was received.

The evening was given over to entertainment, dancing, and the distribution of prizes, with everyone in attendence taking home a gift.

The new officers of the Section for the 1956 season were introduced from the rostrom. They are: President, Jacob Kuhn of MacDonald Plastic; Vice-President, Fred E. Schwab of Schwab Plastics; Secretary, John Slater of Tennessee Eastman; Treasurer, Donald H. Kocher of Monsanto Chemical.

Judging from the enthusiastic response, the way has been paved for a repetition of this party next year and, judging from the comments of the guests, the Ball Park will have to be obtained to handle the crowds.

Southern

Section Elects New Officers

C. Veazey LaCraw

The Southern Section held its second annual Christmas dinner-dance at the Red Fez Club in Atlanta, Ga., on December 19, 1955. The program included an excellent steak dinner and entertainment furnished by Bob "Cousin Lem" Corley, a local disc jockey. A wonderful time was had by all.

The new officers for the coming year were announced as follows: President, C. Veazey LeCraw, Lockheed Aircraft Corp.; Vice-President, Jones C. Beene, III, Plastic Industries, Inc.; Secretary, Raymond W. Kruse, Rohm & Haas Co.; and Treasurer, Herbert F. Loring, Gladwin Plastics, Inc. The three new board members are as follows: Thomas H. Hart of Hart Engineering & Sales Co., Jones C. Beene, III, and Herbert F. Loring. The remaining six board members are Clarence E. Ballentine, Scripto, Inc., Robert D. Jones, The Glidden Co., Bradford L. Nicholson, Manufacturers' Agent, Harold J. Torgesen, Advertising Consultant, Raymond W. Kruse, and C. Veazey LeCraw.

The Southern Section owes a lot to its outgoing officers under whose leadership the Section ended a very successful second year. It is especially indebted to Leo J. Diamond, Koppers Co., who served as president until his transfer to Chicago in June; to Clarence E. Ballentine, Vice-President who did a capable job of taking over for Leo during the latter part of the year; and to Bradford L. Nicholson, who served as secretary and program chairman, both of which are difficult and time-consuming jobs.

Painting Plastics . . .

(Continued from page 19)

head for use in control, and the most widely accepted angle for the light source appears to be 60°.

Such factors as pigment-to-resin ratio, size of pigment particles, and inherent characteristics of the resins may affect gloss. However, these are basic properties of the paint and normally do not change in production to cause variations in gloss. The following situations may arise to cause variations, even though the paint was approved upon receipt as having the proper gloss.

Pigment Settling: A variation in the reflectance of flat and semi-flat finishes from too glossy to excessive flatness may be the result of pigment settling. Heavy flatting agents and even heavy pigments may settle somewhat on long storage. If such paint is used without sufficient mixing, the portion from the top of the container may contain much less than the required amount of pigment and flatting agent. Thus, it may spray to a glossy film. As paint is used toward the bottom of the can, the amount of pigment and flatting agent increases so that the paint film will be too flat.

The solution is proper inspection of the material upon receipt and again when it is mixed for the spray line. However, if such a variation in gloss is detected after the spray line has been in operation, all paint remaining in non-agitated tanks and in partially emptied cans may be off quality because of the withdrawal of a portion that was not thoroughly mixed.

Dry Spray: A reduction in gloss and a rather rough surface which has the appearance of accumulated dust may be the result of dry spray.

Dry spray is the result of the removal of too much solvent between the spray gun and the plastic, causing dry or nearly dry particles of paint to strike the surface. There is no chance for proper film formation, since there is practically no flow-out or leveling. Discrete particles remain as a spongy coat with no toughness and no adhesion to the plastic.

Dry spray is likely to occur when paint is formulated for very quick drying by reducing the high boiling solvent or thinner to a minimum. Spray gun settings allowing too much air under high pressure and too little paint to pass through the spray nozzle favor dry spray even with well formulated paint.

The solution to dry spray problems may include gun adjustment for more paint and less air, and more high boiling thinner in the paint. A wetter film must be sprayed.

Improper Thinning: Gloss may be reduced by the use of inactive solvent or thinner in amounts sufficient to throw the resins out of solution while mixing or in the paint film as it dries. The results may vary from a slight clouding of the film, in mild cases, to an appearance somewhat resembling dry spray or humidity blush, in extreme cases. If the resin is thrown completely out of solution, the film will be irregular and composed of particles that may have no adhesion to the plastic. Flat finishes may also lose adhesion as a result of too much inactive thinner, even though there is no visible gloss change.

This problem might be expected if paint is overcorrected to avoid crazing of strained parts. Any solvent that reduces the activity of the paint for a particular plastic may likewise reduce the activity for the paint resins. However, this is not always the case.

The solution to this problem is proper thinning.

Humidity Blush: Humidity blush may cause a loss of gloss quite like that caused by excessive inactive thinner. As paint is sprayed and as solvents evaporate from the wet film, moisture may condense from the atmosphere into the paint film effectively diluting or reducing the activity of the solvent. At a point, the water-solvent mixture becomes such a poor solvent for the paint resins that they are thrown out of solution. The dry paint film will be rough and irregular, composed of discrete particles of resin which do not adhere to one another or to the plastic surface. Humidity blush can often be detected by spraying two panels and placing one in a stream of forced hot air while allowing the other to dry at room temperature.

The answer to blush is good paint and proper thinning. Since loss of adhesion usually accompanies blush, the Scotch Tape test frequently will reveal instances of slight blushing which have not affected gloss. Blush should be suspected at any time where there is a loss of gloss.

(This article will be concluded in the next issue of SPE Journal.)

Philadelphia

New Officers Are Announced

C. H. Jepson

One hundred and twenty-nine members and guests came to a dinner and dance held by the Philadelphia Section in Franklin Hall at Franklin Institute. It had been the practice for several years to hold a Ladies Night meeting in December, but this was the first time that the evening was entirely social in nature. There were table favors for all and a total of 65 prizes awarded. The evening was a real success, and even the odd man (Number 129) had a good time. Several of the members felt the urge to sing, and one group including Bill Bracken, Sam Greenwood, John Raven, Jim Rex, John Jackson, and Adolph Kissileff drew loud and long applause for their musical talent.

Ed Derowski, Philadelphia Section President for 1955, announced the results of the elections of new officers for 1956, new board members, and the new national council representative. The officers for 1956 are: Edward Fitzpatrick, President; Carl Jepson, Vice President; Henry Fuggitti, Secretary; and Samuel Greenwood, Treasurer. Norman Skow is the new National Director. The three Section Directors elected for three-year terms are Ernie Bernhardt, Herb Clark, and John Jackson.

Incidentally, the new President and his wife are receiving congratulations these days for several reasons. They were unable to attend the dance because of other urgent business—a new baby girl.

SPEAKING OF EXTRUSION

Edited by **R. D. Sackett**
Technical Service Associate
Monsanto Chemical Company
Springfield, Massachusetts

Is Adiabatic Extrusion Practical?

By: Ernest C. Bernhardt
Sales Service Laboratory
Polychemicals Department
E. I. du Pont de Nemours & Co., Inc.

When extruders are operated at high speeds in order to reach maximum production, it is commonly noted that the heat transfer through the barrel is reduced, and heat generated mechanically within the resin assumes greater importance in determining the extrudate temperature. As a consequence, the principles of adiabatic extrusion are attracting wide interest, and the question in the title of this discussion is often asked.

DEFINITIONS

The answer to this question will depend on the background of the person to whom it is directed.

Theoretical Adiabatic Extrusion

A person who wishes to give a fundamental engineering answer has but one choice. He must say that adiabatic extrusion is impractical, because it cannot even be achieved in practice. True adiabatic extrusion means extrusion without any heat transfer, either through the barrel or along the length of it. While heat transfer through the barrel can be reduced to insignificance, it is virtually impossible to eliminate the transfer of heat along the length of the machine in the heavy wall of the barrel and the body of the screw. Heat will always tend to be transferred from the hot forward portion of the machine to the relatively cool hopper section. True adiabatic extrusion could only be achieved if the extruder barrel and screw were constructed of an insulating material.

Achievable Adiabatic Extrusion

A second way of looking at adiabatic extrusion is to consider the entire extruder barrel and screw as one thermally insulated system. In such a system it is possible to supply all of the heat to melt the polymer by mechanical work, and it is valid to consider this as adiabatic extrusion.

In such a system, the heater bands on the barrel would supply only enough heat to counteract radiation losses from the barrel. No heat would be transferred from the heater bands into the stock.

In this type of extrusion operation, adjustment in screw speed and in die resistance are the only variables which can be used to control stock temperature. It is necessary to have a variable die resistance (e.g. a die valve). By increasing the die restriction and increasing screw speed, the melt temperature can be raised without altering the delivery rate from the extruder.

This type of adiabatic extruder operation has been studied and thoroughly evaluated (1). Fig. 1 shows a typical theoretical performance diagram for adiabatic extrusion and shows the interrelationship of die restriction, screw speed, stock temperature, and output. For the remainder of this discussion, we will refer to this type of extrusion operation when we use the term "adiabatic" extrusion.

Extrusion Dominated by Mechanically Generated Heat

In the public mind a third and somewhat inaccurate concept of "adiabatic" extrusion has established itself. In this case, the term refers to an extrusion operation in which very little heat is applied through the outside wall of the extruder, but no effort whatever is made to **minimize** heat transfer through the barrel. In this operation the extruder simply generates so much heat by mechanically working the resin that of the total heat in the material very little, if any, is supplied by transfer through the barrel. As a matter of fact, in some instances heat may even be removed through the barrel wall.

(1) *"Adiabatic Extrusion of Polyethylene," E. C. Bernhardt and J. M. McKelvey, SPE Journal, Vol. 10, No. 3, March 1954.*

In order to reserve the term "adiabatic" extrusion for an operation in which a conscientious **effort** is made to actually minimize heat transfer through the barrel wall, it would be well to describe this third type of operation by a different term. For the remainder of this discussion, it will be referred to as "Extrusion Dominated by Mechanically Generated Heat."

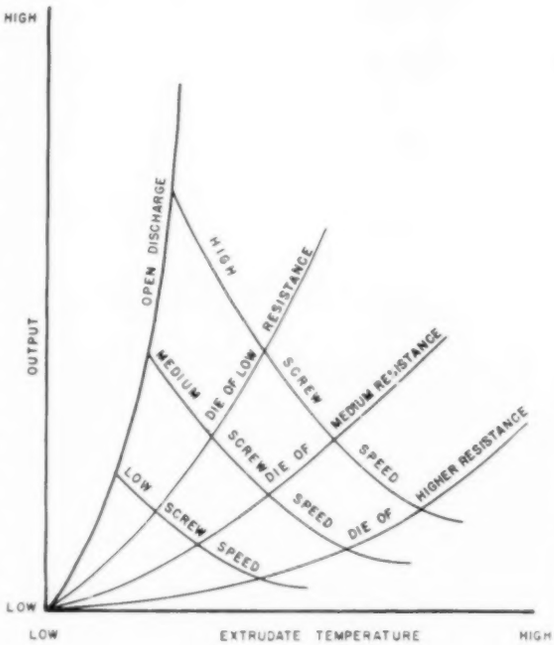
It will, of course, be recognized that no extrusion can take place without some heat being generated mechanically. The action of the screw always causes a shearing action to take place within the viscous melt in the screw channel, and this naturally uses up mechanical work. This mechanical work causes the melt temperature to rise as the polymer is conveyed along the screw channel. Screw speed, die restriction, screw design, and the viscous properties of the melt will determine the amount of heat which is generated mechanically during the extrusion operation.

PROS AND CONS

Now that the principal terms have been defined, the original question concerning the practicality of adiabatic extrusion can be taken up.

Adiabatic extrusion as defined here has a number of important advantages as well as limitations:

Its first advantage is that the ultimate capacity of an adiabatically operated extruder is limited only by the speed and power which the drive can supply. Therefore, very high outputs are theoretically possible even with very small size extruders. The output



TYPICAL PERFORMANCE DIAGRAM FOR ADIABATIC EXTRUSION

FIGURE 1.

is no longer limited by the fixed heat transfer area of the barrel.

This is of particular importance in very large extruders where the ratio of area available for heat transfer to the theoretical extrusion rate becomes small. The heat transfer area is roughly a function of the square of the screw diameter, while the theoretical pumping capacity is a function of the cube of the screw diameter. Thus, full advantage of large extruders will be obtained only when the operation is carried out with heat that is predominantly mechanically generated. We have referred to theoretical output in this discussion, because in actual practice extrusion rates are more in proportion to the square of the diameter, indicating that heat transfer is controlling the process.

A second advantage of adiabatic extrusion is that since the heat in the polymer is generated within the resin through mechanical working, the need of transferring heat from external sources through a high temperature gradient within the melt can be avoided.

The greatest limitations of adiabatic extrusion are that the output rate or the temperature of the extrudate can be controlled only through simultaneous changes of screw speed and die restriction. The need for these coordinated, simultaneous changes makes it difficult to adjust melt temperature or flow rate accurately and rapidly. In addition, the temperature of the melt will be sensitive to small changes in the viscous properties of the melt.

On the basis of these limitations, it must be concluded that adiabatic extrusion as defined here is definitely not practical.

The case of "Extrusion Dominated by Mechanically Generated Heat" is altogether different. Here it is possible to employ the principles of adiabatic extrusion to advantage without running into its shortcomings.

In this type of extrusion, the screw is designed for adiabatic operating temperatures less than those actually desired. Transferred heat is used to bring the stock to precisely the desired temperature. The final fine control of stock temperature can then be obtained through the use of barrel heaters operated through control instruments. No effort is made to limit heat transfer through the barrel.

It can be readily seen that in this type of extrusion operation we retain the advantages which adiabatic extrusion offers:

(1) higher ultimate output, unlimited by the fixed heat transfer area of the barrel, and
(2) avoidance of high temperature gradient within the melt.

Since the final precise control of stock temperature is still brought about through control instruments, it is simple to make the usual independent adjustments of stock temperature or extrusion rate without having to resort to complicated corrections of die restriction coordinated with adjustments of screw speed.

The design of metering type screws to generate the right amount of heat by mechanically working the polymer is not difficult. It has been shown that the theoretical calculations are applicable and check well with actual performance.

Metering type screws for polyethylene resins, acrylic resins, and nylon resins have gained wide acceptance in the field. For these screws the dimensions have been calculated taking adiabatic principles into account, and allow for the viscous properties of the particular resin (2).

However, in order to employ extrusion in which mechanically generated heat dominates and is used to significantly extend the operating range of the machine, it is still necessary to have an extruder geared to operate over a wide range of screw speeds, and capable of delivering ample power so that appreciable mechanical work can be converted into sensible heat in the material.

The question which frequently arises as a consequence is the following:

To obtain a given extruder output, is it best to use a relatively small extruder "hopped up" and designed to take maximum advantage of adiabatic principles by a very refined design, or is it more economical to install a generous size machine where heat transfer can be used more readily to control extrusion conditions, and in which small design details will not play as great a part in the performance? Obviously, this is a question of degree and can be answered only when the circumstances surrounding a particular problem are known.

CONCLUSION

In conclusion, it might be stated that an understanding of adiabatic principles is important in the design of efficient extrusion equipment.

"Extrusion Dominated by Mechanically Generated Heat" definitely is practical, and makes it possible to extend the operating range of extruders. Some mechanically generated heat is present in all extrusion operations. The degree to which it should be employed for greatest economic advantage will depend upon the circumstances of each particular problem.

(2) *Technical Bulletins: X-70, X-72 and X-40, Polychemicals Dept., E. I. du Pont de Nemours & Co., Inc.*

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Peter W. Simmons, Secretary
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Wayne Pribble, Treasurer
(Pribble Plastics Products, Inc.)

SPE's 12th Conference Sets New Record

The word to describe SPE's 12th Annual Conference is "fabulous." Registration hoped for was 2,000; actual registration exceeded 2,500, making this conference largest by far. Best index of the crowd is the unhappy elevator starter who was carried by the pressure into the elevator and had to make a round trip to get out.

Size of meetings posed problems new to SPE, which will be worked out for the future. But the Statler's largest halls were filled to capacity with many standing at most of the excellent papers presented.

Charters were presented to three new Sections; Osaka, Japan, Kentuckiana and Pioneer Valley (Leominster). About 200 new members were signed up at the registration desk.

SPE's thanks for the splendid company support, to the many fine speakers, and to the Conference Committee.

COMPANY REGISTRATIONS

Adamson-United—Akron 4, Ohio

Advance Solvents & Chemical, Div. of Carlisle Chemical Works, Inc.—New York 16, New York

American Agile Corporation—Maple Heights, Ohio

American Cyanamid Company—New York

American Hard Rubber Company—New York

American Molding Powder & Chemical Corp.—Brooklyn 6, New York

Anchor Plastics Company—Long Island City, New York

Bakelite Company, Division of Union Carbide & Carbon Co., Inc.—New York, New York

Barrett Division Allied Chemical & Dye Corporation—40 Rector Street, New York City 6, New York

Black-Clawson Company, Dilts Division—Fulton, New York

Twelfth Annual SPE Technical Conference Committee

THE TWELFTH ANNUAL TECHNICAL CONFERENCE COMMITTEE, reading left to right: (front row) **D. F. Siddall,** Program; **H. D. Oliver, Jr.,** Advance Registration; **W. E. Manring,** Speakers; **F. A. Martin,** General Chairman; **S. M. Crawford,** Co-Chairman; **E. P. Moslo,** Treasurer. (Rear row) **R. C. Lopez,** Company Registration; **H. M. Olson,** House; **R. B. Treer,** Sgt. at Arms; **Edward Campi,** Prizes & Favors; **A. R. Morse,** Printing; **H. M. Zimmerman,** Registration Chairman; **K. M. Keller,** Banquet. Not present: **Jack R. Pecktal,** Sec'y. & Ladies' Program; **Hugh Winn,** Program; **B. J. Wulf,** Printing; **S. A. McElroy,** Publicity.

Boonton Molding Company—Boonton, New Jersey
Borden Company, Chemical Div., Durite Products Dept.—Philadelphia 36, Penna.
Buckeye Molding Company—Miamisburg, Ohio
Casco Products Corporation—Bridgeport 2, Connecticut
Catalin Corporation of America—New York 16, New York
Celanese Corporation of America—Newark, New Jersey
Chippewa Plastics, Inc.—Chippewa Falls, Wisconsin
Ciba Company, Inc.—New York 14, New York
Cincinnati Testing & Research Laboratories—Cincinnati 2, Ohio
The Colonial Plastics Mfg. Company—Cleveland, Ohio
Columbian Carbon Company—New York 17, New York
Continental Diamond Fibre—Newark, Delaware
Cosmo Plastics Company—Cleveland, Ohio
Crown Cork & Seal Company, Inc.—Baltimore 3, Maryland
Crucible Steel Co. of America—Syracuse 1, New York
Damac Tool Company—New York, New York
A. P. DeSanno & Son, Inc.—Phoenixville, Penna.
Detroit Mold Engineering Company—Detroit 12, Michigan
Dixon Corporation—Bristol, Rhode Island
The Dover Molded Products Company—Dover, Ohio
The Dow Chemical Company—Midland, Michigan
E. I. duPont de Nemours & Co., Inc.—Wilmington, Del.
Durez Plastics Division, Hooker Electro-Chemical Co.—N. Tonawanda, New York
Eastman Chemical Products, Inc.—Kingsport, Tennessee
Electromold Corporation—Trenton, New Jersey
Emery Industries, Inc.—Cincinnati, Ohio
Enjay Company, Inc.—Elizabeth, New Jersey
Evans Research and Development Corporation — New York, New York
The Fabri-Form Company—Byesville, Ohio
The Fellows Gear Shaper Co.—Springfield, Vermont
Ferro Chemical Corporation—Bedford, Ohio
Fiberite Corporation—Winona, Minnesota
Firestone Plastics Company—Pottstown, Pennsylvania
Foster Grant Company, Inc., Petrochemical Div.—Leominster, Mass.
The Fuller Brush Company—Hartford, Connecticut
General American Transportation Corp.—Chicago, Illinois
General Electric Company, Chemical & Metallurgical Div. — Pittsfield, Massachusetts
The General Tire & Rubber Company, Chemical Division—Akron 9, Ohio
B. F. Goodrich Chemical Company—Cleveland, Ohio
Goodyear Tire & Rubber Company, Inc., Chemical Div.—Akron 16, Ohio
W. R. Grace and Company—New York, New York
H. V. Hardman Company, Inc.—Belleville, New Jersey
The Harshaw Chemical Company — Cleveland 6, Ohio
Hercules Powder Company — Wilmington, Delaware
The Hydraulic Press Mfg. Company—Mt. Gilead, Ohio
Improved Machinery, Inc.—Nashua, New Hampshire
Industrial Mfg. Corp—Indianapolis 4, Indiana

Otto Wulfert of Wagner Electric Co., was the winner of the grand door prize given at the banquet at SPE's twelfth Annual Conference in Cleveland, January 19th. The boat, a 14' Crosby Hydrodyne was given by Crosby Aeromarine Co., Div. of Midwestern Industries Corp., Grabill, Indiana; the resin donated by the Glidden Co. of Cleveland; the glass roving by Hess Goldsmith Glass Co. of New York; and the glass cloth by Exeter Mfg. Co., of Exeter, New Hampshire.

Injection Molders Supply Company—Cleveland 20, Ohio
International Molded Plastics, Inc.—Cleveland, Ohio
The M. W. Kellogg Company—Jersey City, New Jersey
Koppers Co., Inc., Chemical Div.—Pittsburgh 19, Penna.
Kordite Co., Inc.—Macedon, New York
W. T. LaRose & Associates, Inc.,—Cohoes, New York
Lester Engineering Company—Cleveland 13, Ohio
Lewis Welding & Engineering Corp.—Bedford, Ohio
Luria-Cournand, Inc.—Havre De Grace, Maryland
Manco Products, Inc.—Melvindale, Michigan
Mastro Plastics Corporation—Bronx, New York
Michigan Plastic Products, Inc.—Grand Haven, Michigan

(Please turn to page 53)

Membership Competition Chart

Section	Membership Chairman	Members July	Members Oct.	Quota To Go	Quota Met
Baltimore-Washington	Bernard E. Franklin	81	91	17	41%
Buffalo	Ranson D. Thilk	76	77	15	33%
Central Indiana	C. R. Smith	46	54	15	113%
Central Ohio	William Croll	50	50	15	13%
Chicago	E. E. Eckenbeck	354	373	71	20%
Cleveland-Akron	Granville H. Shirley	219	233	45	22%
Connecticut	Lewis Pentland	102	110	21	24%
Detroit	John Slater	201	216	40	28%
Eastern New England	Joseph Clancy	163	176	35	49%
Golden Gate	James Smith	42	46	10	20%
Kansas City	Jerome Kivett	52	52	15	27%
Kentuckiana	J. Feller	4	24		
Miami Valley	R. Wright	99	105	21	24%
Milwaukee	Charles E. Egan	42	43	10	70%
Newark	Frank L. Quimby, Jr.	428	442	85	21%
New York	Arthur S. Jacobs	443	474	92	29%
Northern Indiana	Phil Leonard	23	23	10	20%
Northwest Pennsylvania	D. A. Leet	86	88	20	20%
Ontario	G. Rea	122	122	21	24%
Pacific Northwest	Don LeGassey	32	33	10	0%
Philadelphia	Edward Fitzpatrick	230	249	47	36%
Pittsburgh	Charles G. Snyder	61	61	15	27%
Quebec	J. Bonnett	52	52	10	0%
Rhode Island & SE Mass.	Sidney Lohman	107	109	22	18%
Rochester	Albert F. Patterson	83	87	20	85%
St. Louis	Chris Kacalieff	73	76	15	53%
Southeastern Ohio	Paul M. Smith	43	43	10	0%
Southern California	R. Griffith	138	150	28	57%
Southern Section	R. W. Kruse	60	62	15	27%
South Texas	T. Robb	41	41	10	0%
Toledo	W. R. Anderson	66	70	15	40%
Upper Midwest	Mrs. L. Bolstad Orville Hultgren	69	75	15	80%
Western New England	W. G. Clark	202	202	40	23%
Worcester-Leominster			4		
Non Section		58	69		
TOTALS		3951	4182	830	33%

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2 Small total water capacity—no excess thermal carryover either way.

3 Super-sensitive, accurate HEATING CONTROL with extremely fast reaction time.

4 Flexible, modulating COOLING CONTROL—not on or off.

MODEL 6003 — DUAL

MODEL 6002 — DUAL

The mobile temperature control unit functioning in leading plastics plants from coast to coast. Ready to operate when connected to electricity, water and drain.

MODEL 6012 — SINGLE

MODEL 6003 — DUAL
A compact unit designed for permanent installations. (Can be equipped with casters). Requires approximately 50% less floor space than Model 6002 with same capacities.

MODEL 6012 — SINGLE
A highly efficient unit for use where a single stabilized temperature is adequate as in small molds or molds with shallow cavities. Works well where metal molds provide for water circulation in vacuum forming, as well as to control temperatures of calender rolls in sheet extrusion. Can be used with above DUAL models where MORE than TWO temperatures are required.

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INDUSTRIAL CONTROL DIVISION

STERLING, INC.

3736 N. Holton Street • Milwaukee 12, Wis.

Export: Omni Products Corp., 460 Fourth Ave., New York 16, N. Y.

PVC Dry Blends . . .

(Continued from page 16)

Gloss is greatly aided by this last-minute heating, and color dispersion is helped greatly.

A word should be said about the Jackson-Church molding machine with the Hendry Screw Preplasticizer, which extrudes plasticized material into the injection chamber. This chamber can be kept at lower temperatures than the heating cylinder of a more conventional machine, say at 260°F or lower. Both the decomposition and plasticizing problems are helped by this machine and increased capacity can be obtained. Savings should soon pay off the added cost, if vinyl is to be molded in large volume output.

To *summarize* briefly, then we can see that injection molded vinyl chloride has a definite place in the materials world, and that it is not merely a substitute for other materials, but has advantages of its own, due to its good strength, colorability, resistance to oils and solvents and excellent electrical characteristics. It can be formulated into a wide range of compounds for many types of end uses.

Molding techniques are similar to those used for other thermoplastics, but the presence of chlorine limits its ability to withstand high temperatures without decomposing; hence cycles and temperatures must be carefully controlled. Variations in formulation also must be taken into consideration in the molding process.

Dry blend is a newer form of PVC consisting of a sandy mix easily colored by tumbling, which has been processed at lower temperatures than pellets and has less heat history. Although more working is necessary in order to properly plasticize it, the economies of smaller inventory, ready availability of material, or of mixing of dry blend by the molder, make it very attractive to him.

Devices such as the Monsanto adjustable nozzle restriction and the Hendry Screw Preplasticizer have been used to great advantage in producing excellent quality injection molded PVC dry blend.

Fig. 4 The Monsanto nozzle for injection molding of PVC dry blend.

Company Registrations . . .

(Continued from page 51)

Molded Fiber Glass Tray Company—Linesville, Penna.
Monsanto Chemical Company—Springfield, Massachusetts
The Morningstar Corp.—Cambridge 42, Massachusetts
Moslo Machinery Company—Cleveland, Ohio
H. Muehlstein Company—New York City, New York
National Aniline Division Allied Chemical & Dye Corp.—New York 6, New York
National Rubber Machinery Co.—Akron 8, Ohio
Naugatuck Chemical Div. of U. S. Rubber Company—Naugatuck, Connecticut
Newark Die Company—Newark, New Jersey
Nixon Nitration Works—Nixon, New Jersey
Omaha Plastics Company—Omaha, Nebraska
Owens-Illinois—Toledo 1, Ohio
Pennsylvania Refining Company—Butler, Pennsylvania
Pribble Plastics Products, Inc.—New Haven, Indiana
Prodex Corporation—Fords, New Jersey
Product Techniques, Inc.—Hudson, Ohio
Reed Prentice Corporation—Worcester, Massachusetts
R & K Tool & Die Company—Cleveland 11, Ohio
Rohm & Haas Company—Philadelphia, Pennsylvania
Shaw Insulator Company—Irvington 11, New Jersey
Shell Chemical Corporation—New York 17, New York
Seiberling Rubber Company—Newcomerstown, Ohio
Smith and Stone Ltd.—Toronto, Canada
Spencer Chemical Company—Kansas City 5, Missouri
Standard Tool Company—Leominster, Massachusetts
F. J. Stokes Machine Company—Philadelphia 20, Penna.
Stokes Molded Products—Trenton 4, New Jersey
Tennessee Products & Chemical Corp.—Nashville, Tenn.
Thermel, Inc.—Chicago 24, Illinois
Trump Plastics, Inc.—Cuyahoga Falls, Ohio
U. S. Industrial Chemicals Co.—New York 16, New York
U. S. Stoneware Company—Akron 9, Ohio
Vichek Tool Company—Cleveland, Ohio
The Warner & Swasey Company—Cleveland 3, Ohio
Watson Stillman Press, Division of Farrel Birmingham Company, Inc.—Roselle, New Jersey
Welding Engineers, Inc.—Norristown, Penna.
Westchester Plastics, Inc.—Mamaroneck, New York
West Instrument Corporation—Chicago 44, Illinois
Wilpet Tool & Mfg. Company—Kearny, New Jersey
Witco Chemical Company—New York, New York
Yates Company—Erie, Penna.
Zenith Plastics Company—Cleveland 14, Ohio

Alpha Plastics, Inc.
Baker Bros., Inc.
A. Bamberger Co.
Bolta Products Div. General Tire & Rubber
Camfield Fiberglas Plastics, Inc.
Cleveland Plastics, Inc.
Connecticut Plastics, Inc.
Fabri-Kal, Inc.
International Molded Plastics, Inc.
Johnson Plastics, Inc.
Loma Plastics, Inc.
Marblett Corp.
Olin Matheson
Plywood Plastics, Div. of Western Electric
S & C Electric Co.
Tracerlab, Inc.
Triangle Conduit & Cable, Inc.

A list of companies contributing door prizes is given on page 8.

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PLASTIC ENGINEER

Graduate Mechanical Engineer experienced in extrusion of plastic products to work in new nylon project as member of Development and Research Team. Excellent working conditions, complete benefit plans. NATIONAL ANILINE DIVISION, Allied Chemical & Dye Corporation, Hopewell, Virginia. Mailing address P.O. Box 831, Hopewell, Virginia. Plant location is one mile North of Hopewell, off State Route 10.

PRODUCTION ENGINEER WANTED

Medium size injection plant in Bridgeport, Conn. seeks young engineer with some plastic experience in production and maintenance supervision, estimating and tool shop contact. Pleasant working conditions and advancement available for the right man. Write full qualifications and expected starting salary. THE VOGEL MFG. COMPANY, P.O. Box 512, Bridgeport, Connecticut.

Transparent Plastics

(Continued from page 30)

are used or where the part is mounted from behind and seen through an undersized opening, there is less of a problem and these are sound solutions if economically practical.

On interior and some automotive applications integrally molded lugs are sometimes used. They can be disguised by locating them in an area of dark paint or "light trap" if the design permits. Another method is to locate them in places easy to camouflage like the centers of letters like O, C, B, R, P, if a medium value or darker background color is possible. Most lugs, however, are located near edges or on the base of the returns. If the first surface meets the return at a sharp angle and no external radius is provided, it is possible to see down through the return and the integral lug is an eyesore (Figure 5). By merely rounding the external corner to a radius of at least the thickness of the material and extending the return rearward a length of at least three times the thickness and carrying the second surface background color around and down the return, it is possible to optically divert the lines of sight so that through a fairly wide viewing angle the rear edge of the return and the lugs are invisible.

Integral lugs, if used, should be as large as possible for strength and a generous fillet should be provided at the inside corners of the base of the lug to offset crack propagation. Lugs should be aligned with the inner edge of the returns so that when the part contracts slightly in cold weather the oversized holes in the cabinet material are not exposed. Allow up to 1/16" plus and minus per foot for thermal movement around the holes for most transparent plastics.

Encouraging developmental work with mastic attachments has been under way for some time and several applications of mastic attachment have been evident in production parts over the past few years. There is reason to believe that vandal-proof mastics will soon be available, permitting virtual elimination of the fastener concealment problem.

By using tinted transparent materials in conjunction with internally reflecting facets or vacuum metalizing, it is possible to simulate gold, copper, chrome and anodized colored effects in a way that overcome some of the drawbacks of the actual metals. Oxidation of metals is eliminated in the brass and coppers and weathering of protective lacquer coatings on metals is eliminated by using the weatherability of some of the transparent plastics to advantage. Fine engine-turned patterns that would be dirt catchers become quite practical when applied to the second surface in the manner of reflex lenses or fresnels, as is evidenced in automotive tail light design.

Possibilities With Electroformed Molds

At the last SPE Conference a paper was delivered on electroformed molds. The designer has been waiting a long time for this to come and it is now possible to reproduce many natural textures for backgrounds where desired. No longer is the designer limited to various degrees of surface finish, engine-turned designs, bars, dots and waffle grids. Within the limits of the dictates of his own good taste he may adopt woven textures, leathers, wood grains, and so on to satisfy the needs of the specific product with regard to background pattern. The 1956 cars show evidence of this broadening application with fine spun finishes, too fine to hob, used as backgrounds around standing design motifs. Dial manufacturers likewise may get flat backgrounds around debossed second surface markings without resorting to hobs, by electroforming from an engraved model.

Conclusion

As stated at the beginning of this paper, design with transparent plastic materials requires specialized knowledge to insure success. Once he has mastered the basic knowledge of the behavior of light in transparent materials, the designer may proceed with assurance to invent new and appealing effects. The design research facilities of the materials manufacturers are available to him whenever he needs additional information but they can only serve him if they know his needs.

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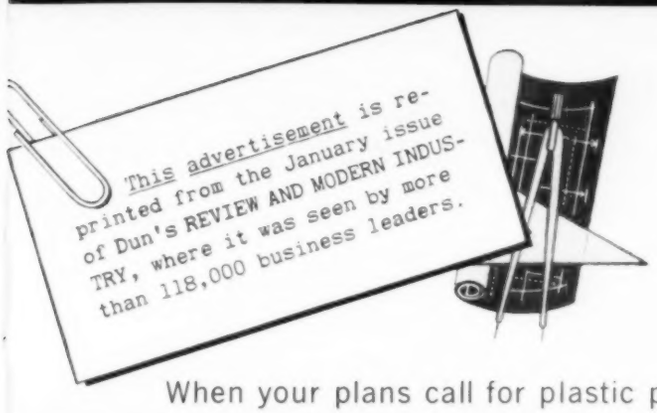
Craftsmen of the 20th Century

No. 11 of a series to introduce you to some of industry's outstanding plastics craftsmen


This advertisement is reprinted from the January issue of Dun's REVIEW AND MODERN INDUSTRY, where it was seen by more than 118,000 business leaders.

In the old days the artisan worked alone, fashioning his masterpieces of metal, wood and glass. Modern craftsmen, inspired by new materials and aided by the methods of mass production, are working in groups to create for the masses instead of the few. By applying their skills to the mastery of plastics, for instance, these specialists are molding products that serve every industry, every home. Two of these 20th Century craftsmen are pictured on this page. Monsanto, a major producer of high-quality plastic materials, salutes these men who are helping to mold America's tomorrow.

When your plans call for plastic parts or products, consult an expert custom molder

Frank E. Schneider, Champion Molded Plastics, Inc., Bryan, Ohio. With 13 years behind him in the coordination of product design with mold engineering, Mr. Schneider now supervises the operation of some of the industry's most complex molds. During the war he assisted in the process development of plastic detonation fuses. Since, he has engineered molded steering wheels, horn buttons, hood ornaments and arm rests for automobiles; and multi-plane compartments for refrigerators. His job encompasses every stage of plastics technology from tool design to finishing.

Donald Paduchowski, Bolta Products Division, General Tire and Rubber Co., Lawrence, Mass. As a real pioneer of plastics molding, Mr. Paduchowski joined Bolta 20 years ago as an operator on one of the first injection molding machines in the northeast. During the war years, he assisted in the development of intricate military parts molded of plastics. A recent accomplishment is a complicated matchbook vending machine. He kept assembly as simple as possible with six basic precision-fitted pieces. Only metal parts required are 2 roller springs and 4 screws.

MONSANTO CHEMICAL COMPANY,
PLASTICS DIVISION, SPRINGFIELD 2, MASS.

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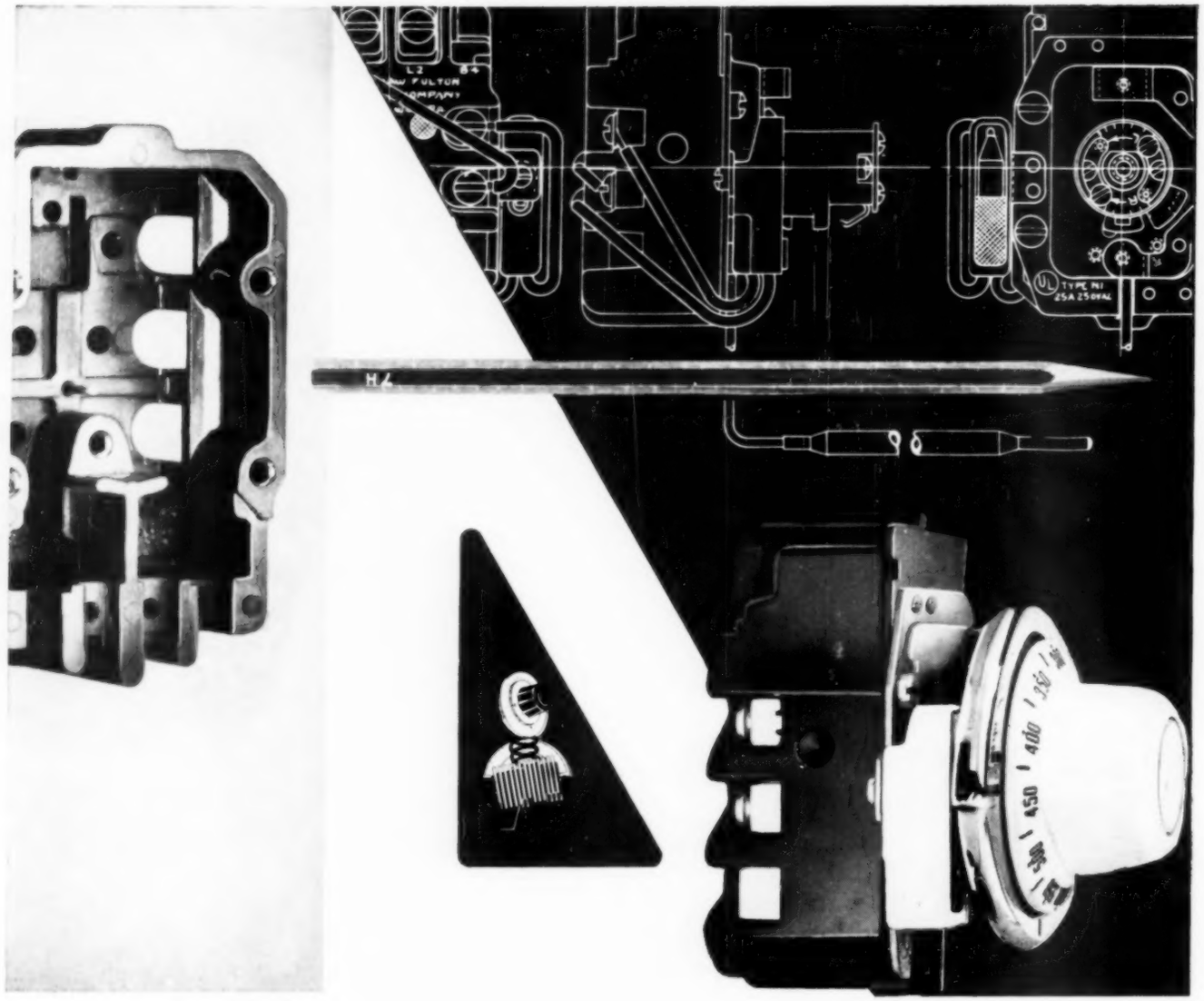

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